There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy.
– Shakespeare

E. N. Tsyganov

Cold Fusion Power, International
OSNovation Systems, Inc., Santa Clara, CA

COLD NUCLEAR FUSION

Joint Institute For Nuclear Research
Bogoliubov Laboratory of Theoretical Physics
Joliot-Curie 6, 141980 Dubna, Moscow region, Russia. July

1983—on the JINR participation in DELPHI experiment

Cold nuclear fusion. *Look beyond the horizon …*

Flammarion, 1888, based on the 16th century vision

Julian Schwinger

Tried to "Look beyond the horizon …

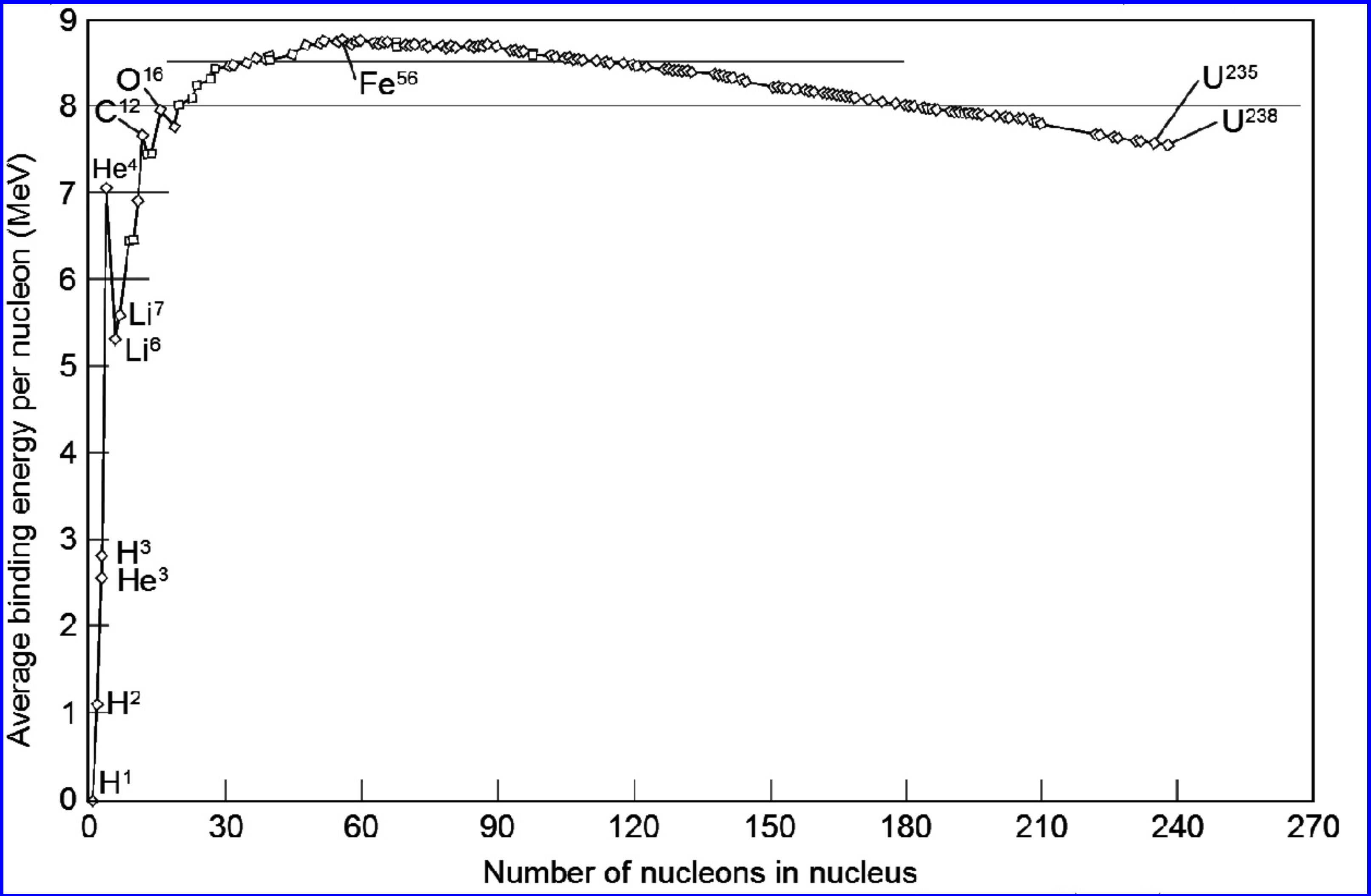
"The pressure for conformity is enormous. I have experienced it in editors' rejection of submitted papers,
based on venomous criticism of anonymous referees.
The replacement of impartial reviewing by censorship
will be the death of science".

Statement made while resigning from the American Physical Society

Richard Feynman

"Physics is the experimental science."

Binding energy



Currently, humanity has come to a stage of development when the struggle for energy resources is becoming especially important. All known sources of energy together will not be able to provide for our demand in the near future. Chemical energy is additionally limited by the so-called greenhouse effect.

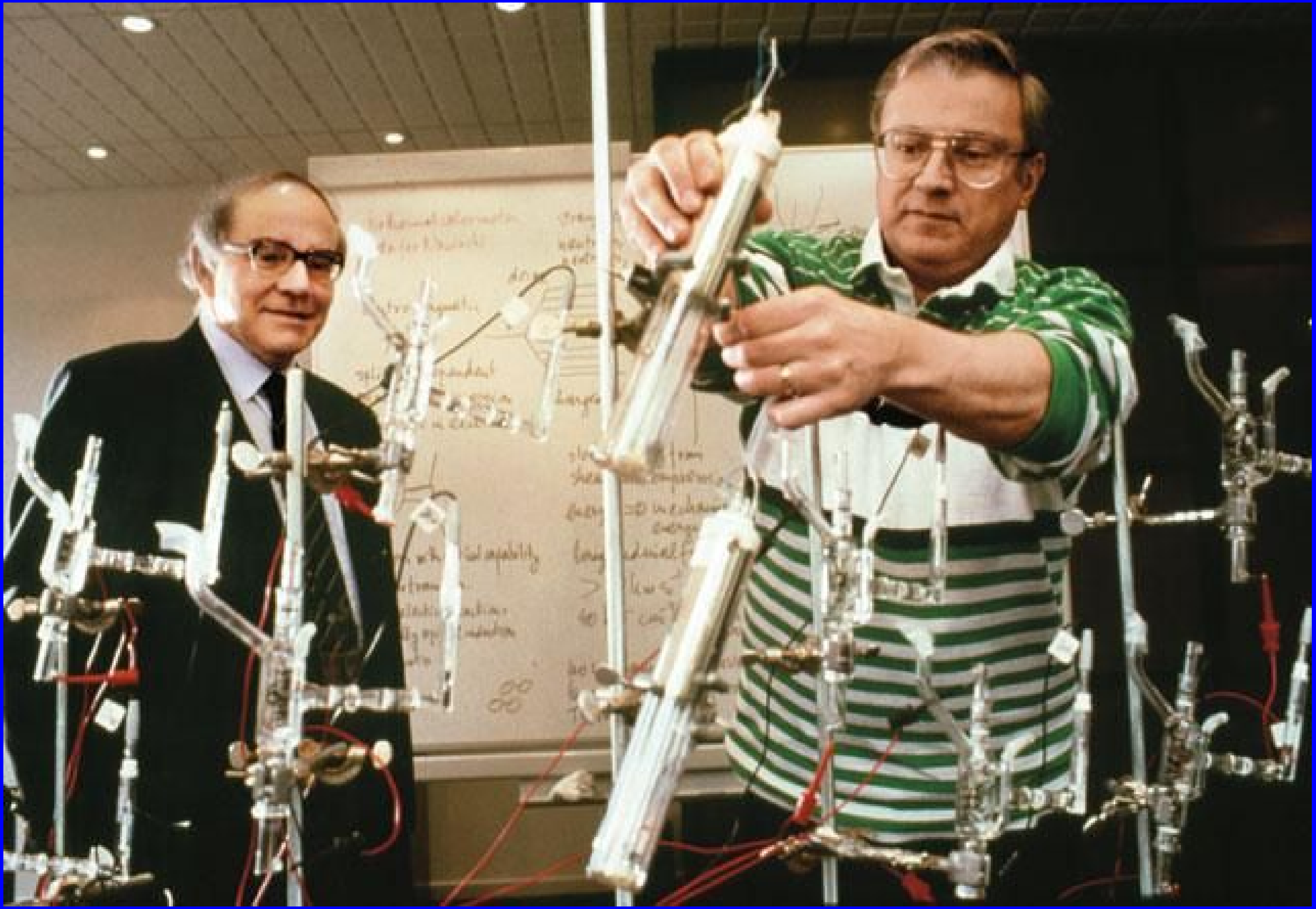
Nuclear energy that based on the use of fissile materials is not the long-term solution to the problem, because stocks of these materials are limited. In addition, the required safe preservation of this radioactive waste for about 10,000 years is a serious problem.

Initial optimistic expectations of a transition to the controlled thermonuclear fusion process never materialized. Technical difficulties of obtaining viable super-hot plasma and the damaging effects of the enormous neutron flux arising as a result of thermonuclear reactions are pushing this development to the more distant and uncertain future.

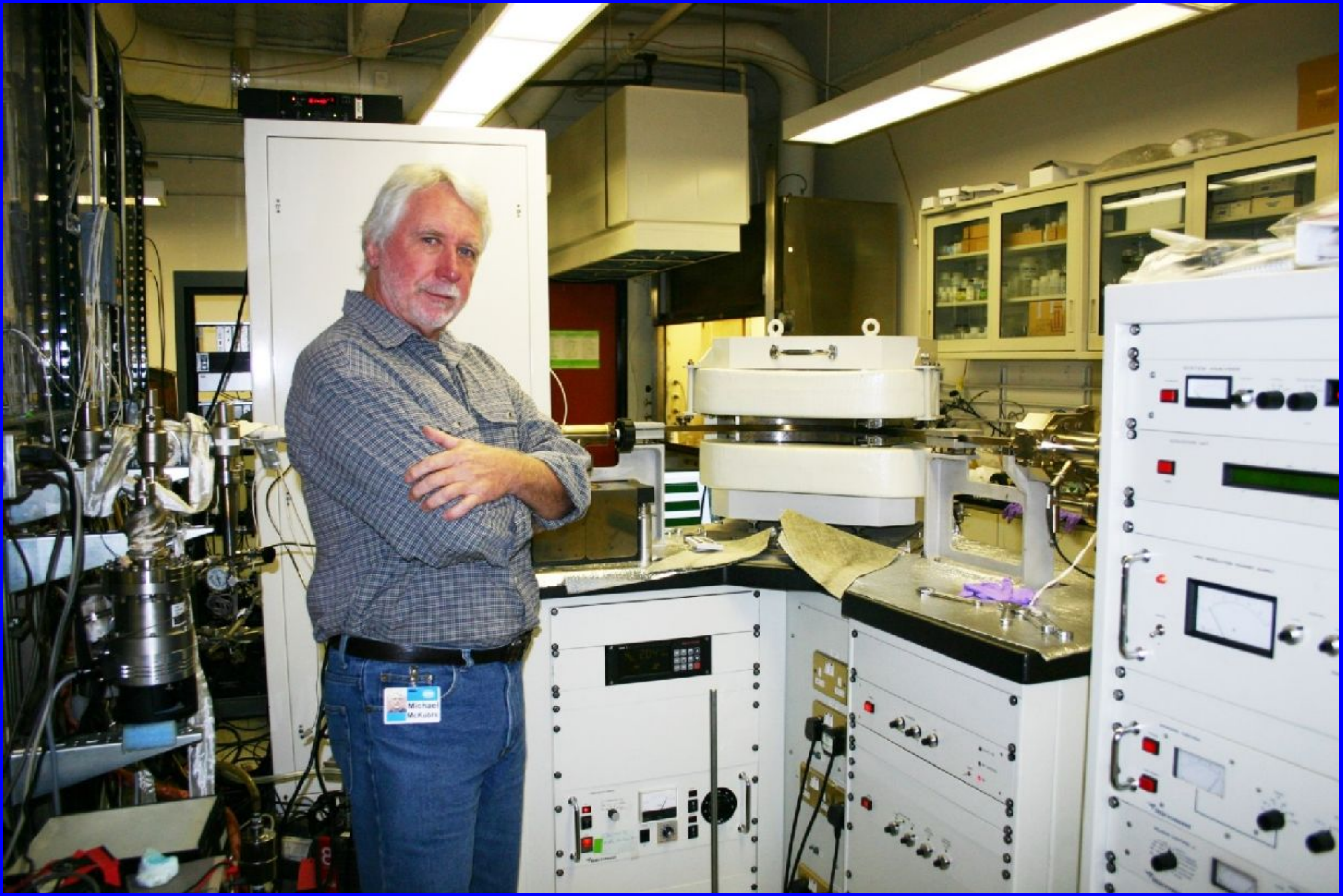
The term “cold fusion” describes a number of processes at relatively low temperature, leading to the generation of heat due to the fusion of two nuclei. Under normal conditions, such processes are prevented by the Coulomb barrier, which precludes the convergence of nuclei. However, about 25 years ago, experiments were performed by Fleischmann and Pons that demonstrated the possibility of “cold” fusion, when nuclear reagents are implanted in metallic crystals.

Quickly rejected by most scholars as irreproducible and not having a consistent theoretical interpretation, these experiments, however, gradually began to give reproducible results. Classic examples are the experiments made by Dr. McKubre and his colleagues at the Stanford Research Institute, International. The results of these experiments demonstrated a reliable heat of nonchemical origin, whereby the effect exceeded about 100 experimental errors.

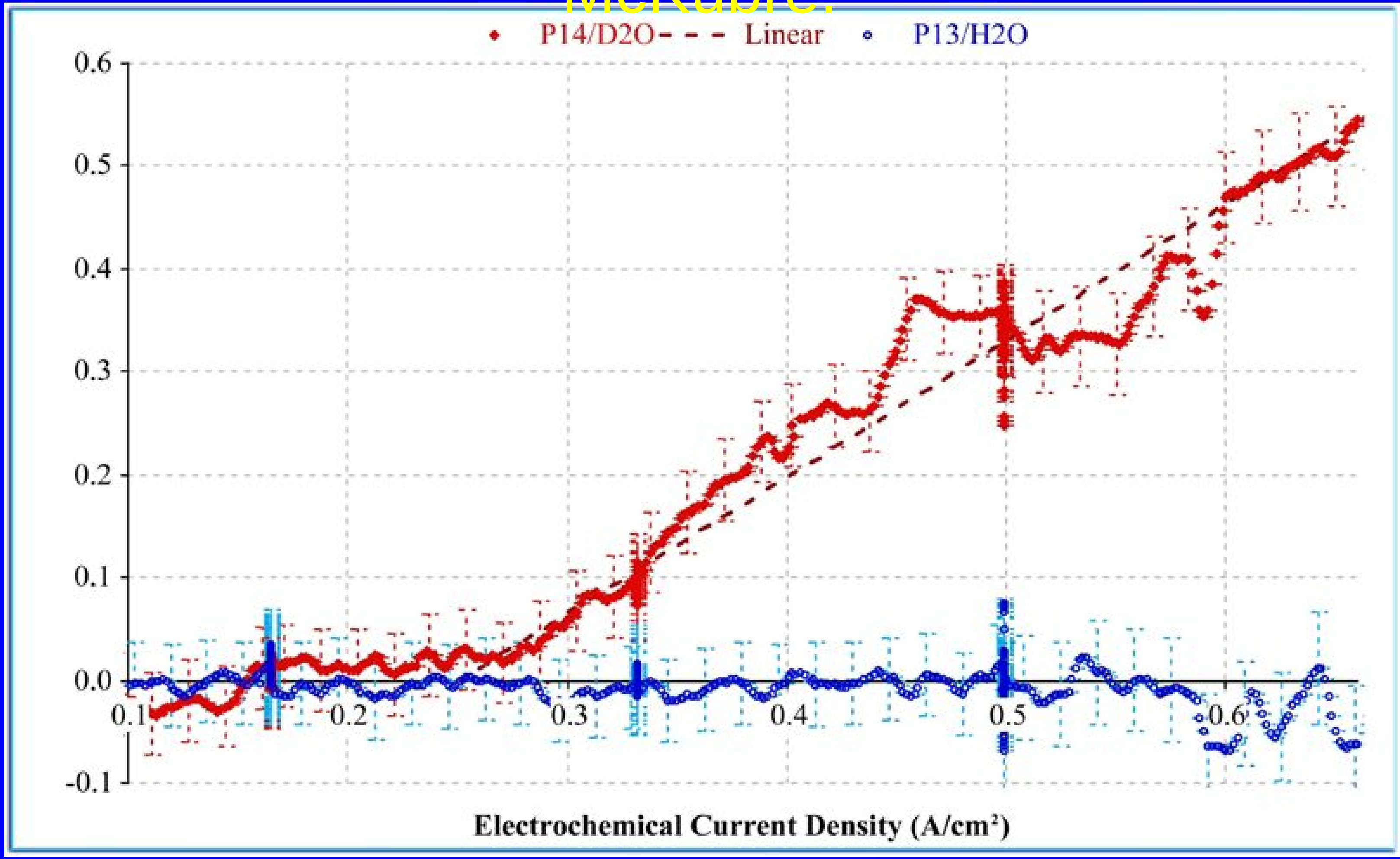
Martin Fleischmann and Stanley Pons, 1989



Dr. McKubre in his laboratory.

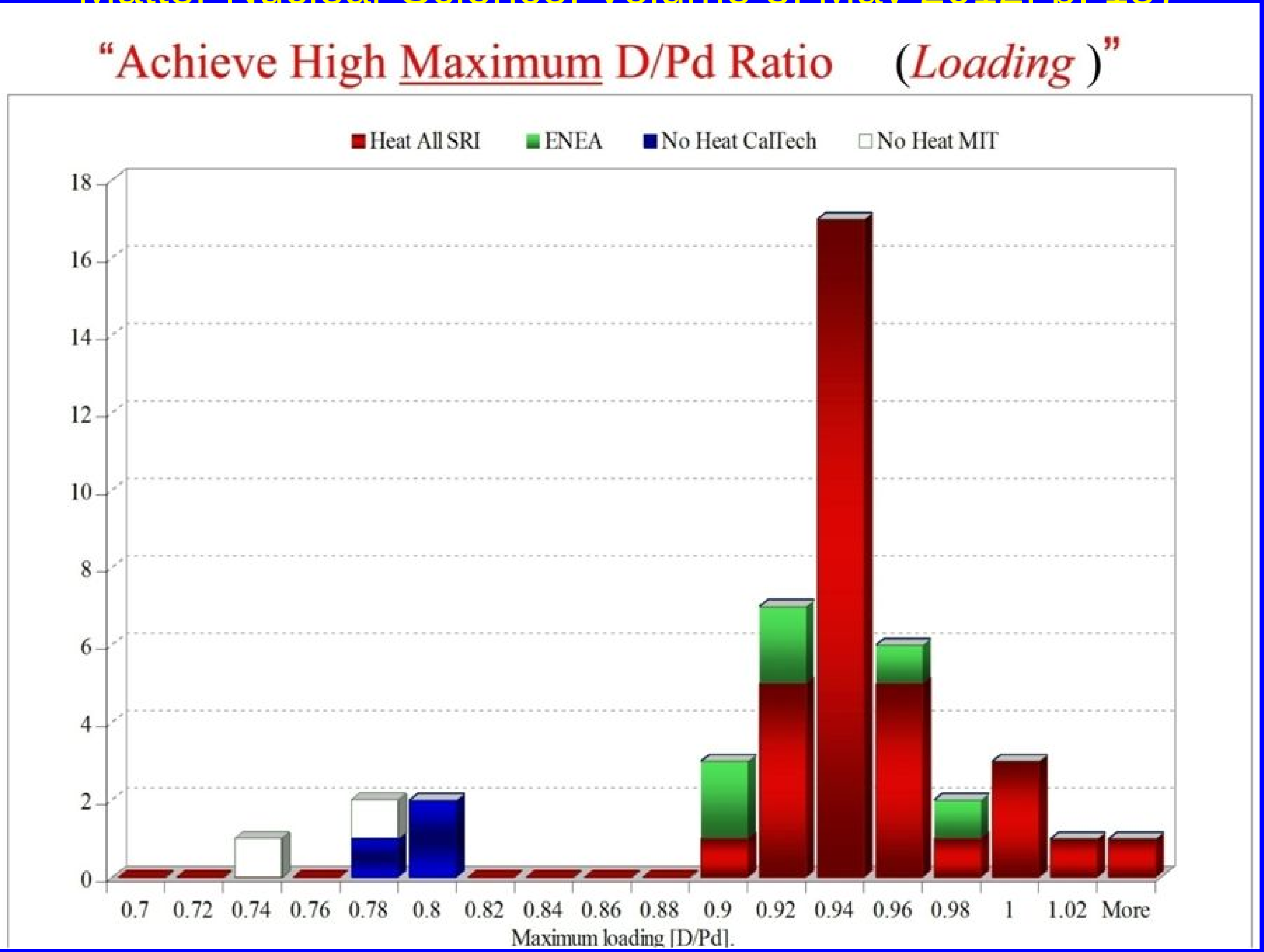


Excess heat in W, depending on the value of the electrochemical current, in the experiments of Dr. McKubre.

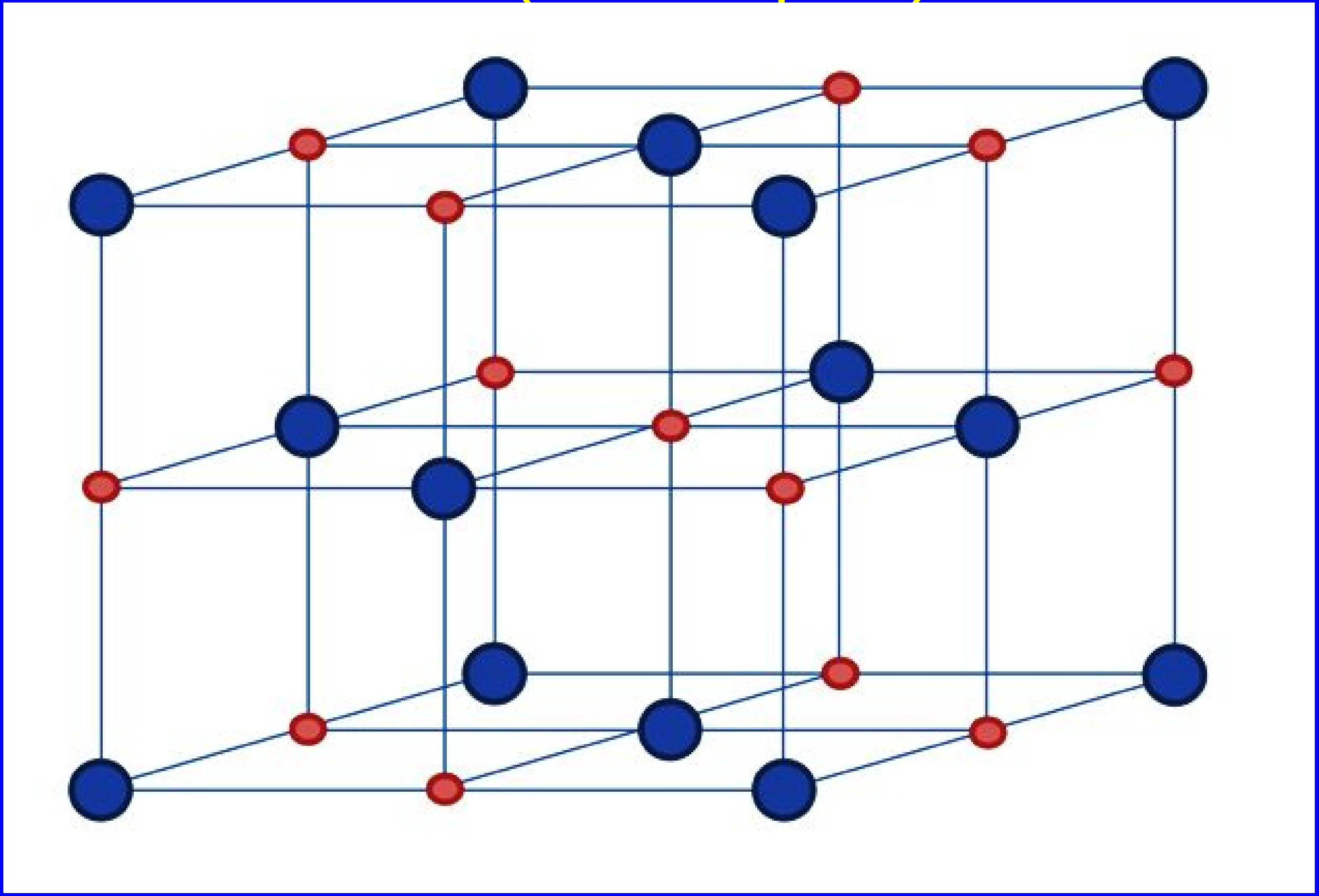


The success of the experiment depends on the concentration of deuterium.

Michael C.H. McKubre, Francis L. Tanzella, and Vittorio Violante, Journal of Condensed Matter Nuclear Science, Volume 8, May 2012, p. 187



The fcc crystal structure. Small circles marked octahedral (the deepest) niches.



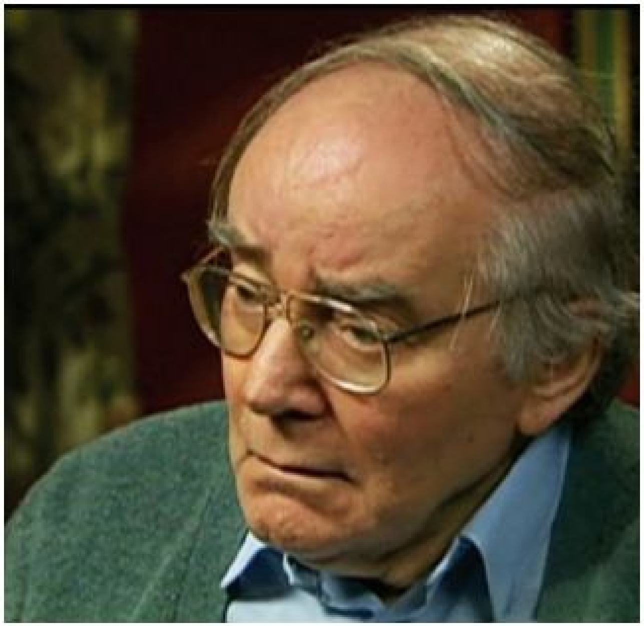
History of cold fusion “in vitro”

1. Martin Fleischmann 1989–2012
2. Michael McKubre 1992–today
3. Yoshiaki Arata 1998–2008
4. Hagelstein and Swartz (MIT) 1992–today

About 20–30 working groups in the US, Western Europe, Russia, Japan, and China.

During the last year, the first four patents were issued for cold fusion (US, Europe, China)

History of cold fusion–the main participants



Martin Fleischmann (1927–2012)
D + D in palladium
1989

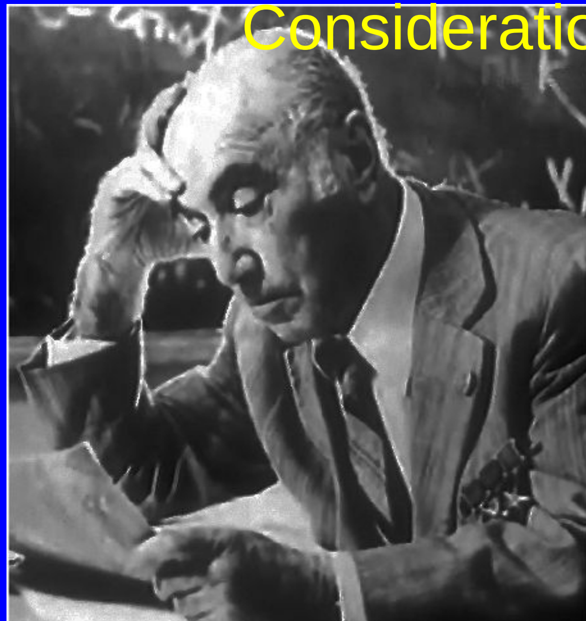
Michael McKubre
D + D in palladium
1992–present

Yoshiaki Arata
D + D a palladium ($ZrO2$)
1998–2008

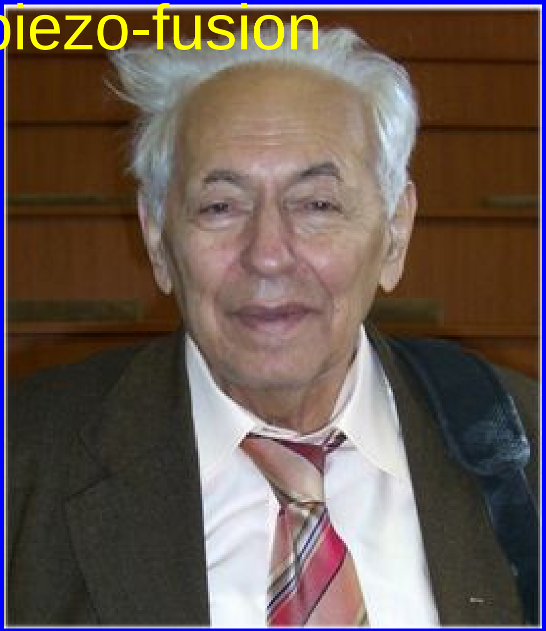
Proof of concept of cold fusion suddenly came from experiments performed with accelerators.

Zeldovich, Ya. B., Gerstein, S. S. (1960). U. F. N., LXXI(4), 1960, 581.

Consideration of piezo-fusion



Ya. B. Zeldovich



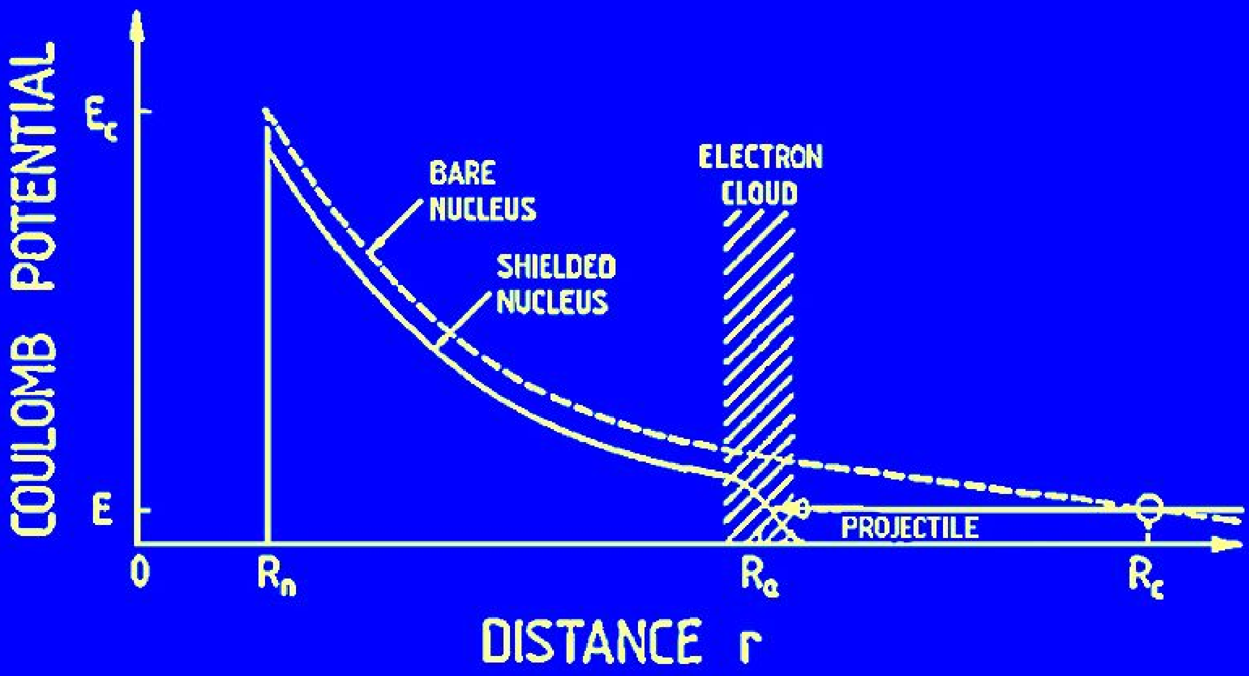
S. S. Gerstein

$$B = \exp\left\{ -\frac{2}{\hbar} \int_{x_1}^{x_2} \sqrt{2M\,(U\,(x) - E)}\, dx \right\} = \exp\left\{ -\frac{2}{\hbar} \sqrt{2M\overline{U}}\,(x_2 - x_1) \right\}$$

The pressure needed to achieve the effect of piezo-fusion happens to be unusually high.

In the quantum-mechanical consideration of the fusion process, electron screening potential Ue is equivalent to the additional energy of particles involved (Assenbaum, Langanke, & Rolfs, 1987). “The penetration through a shielded Coulomb barrier at projectile energy *E* is equivalent to that of bare nuclei at energy *Eeff = E + Ue*.”

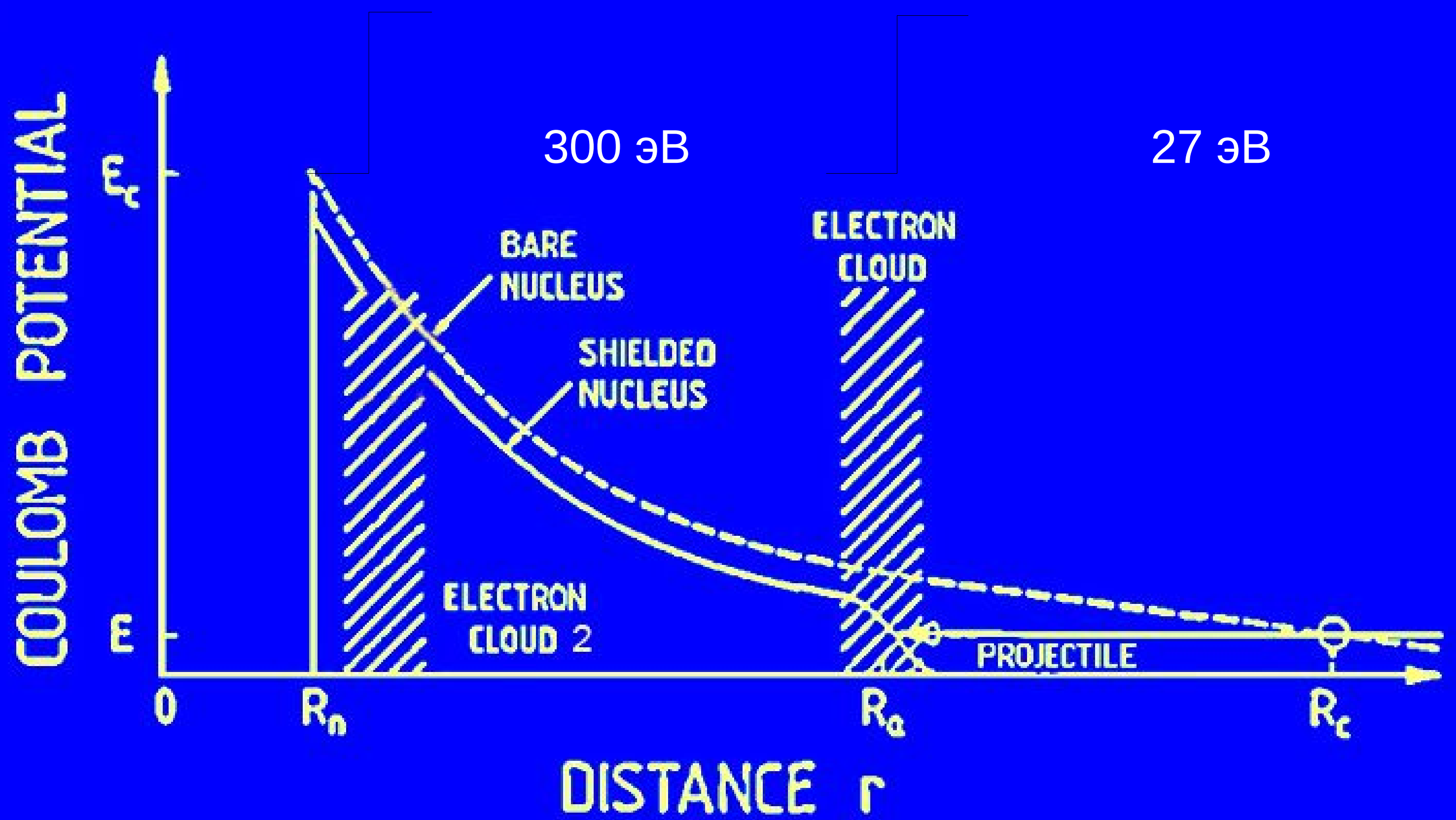
The figure, taken from an Assenbaum paper, schematically depicts a collision of an incident deuterium nucleus with a deuterium atom. For the collision of two free deuterium atoms, this additional energy is equal to *27 eV*.



The accelerator experiments have shown that the magnitude of the screening potential of the impurity atoms in metallic crystals can reach ***300 eV*** and even more. This means that in the DD reaction occurring in the medium of the metal crystal, the implanted deuterium atoms are excited and are no longer spherical. They have more sophisticated electronic orbitals, and they are oriented relative to each other in a certain crystallographic manner. In this case, the nuclei of these atoms can approach each other at a distance substantially less than for a nominal size of the atom without Coulomb repulsion.

Such processes are known in chemistry and are the cause of chemical catalysis. Johannes Rydberg first described these processes in 1888.

Screening potential defines the distance to which the atoms are not experiencing Coulomb repulsion.



The main secret of cold fusion process—overcoming the Coulomb barrier—finally happened to be surprisingly simple. It was first noted by Professor Bressani in 1998 at ICCF-7 conference on the basis of a series of Japanese accelerator experiments performed since 1995. Unfortunately, the cold fusion community at that time did not follow the call of Professor Bressani.

When a solid state target is irradiated by a beam of charged particles, the incident particle captures an electron from the solid body and moves further like an atom, if its velocity does not exceed the so-called Bohr velocity. For deuterons this threshold energy is ~50 keV. This interesting observation was made in the work of Baranov, Y. A., Martynenko, Y. V., Tsepelevich, S. O., Yavlinsky, Y. N. (1988). “Inelastic sputtering of solids by ions”. Physics-Uspekhi, 156(3), p. 477.

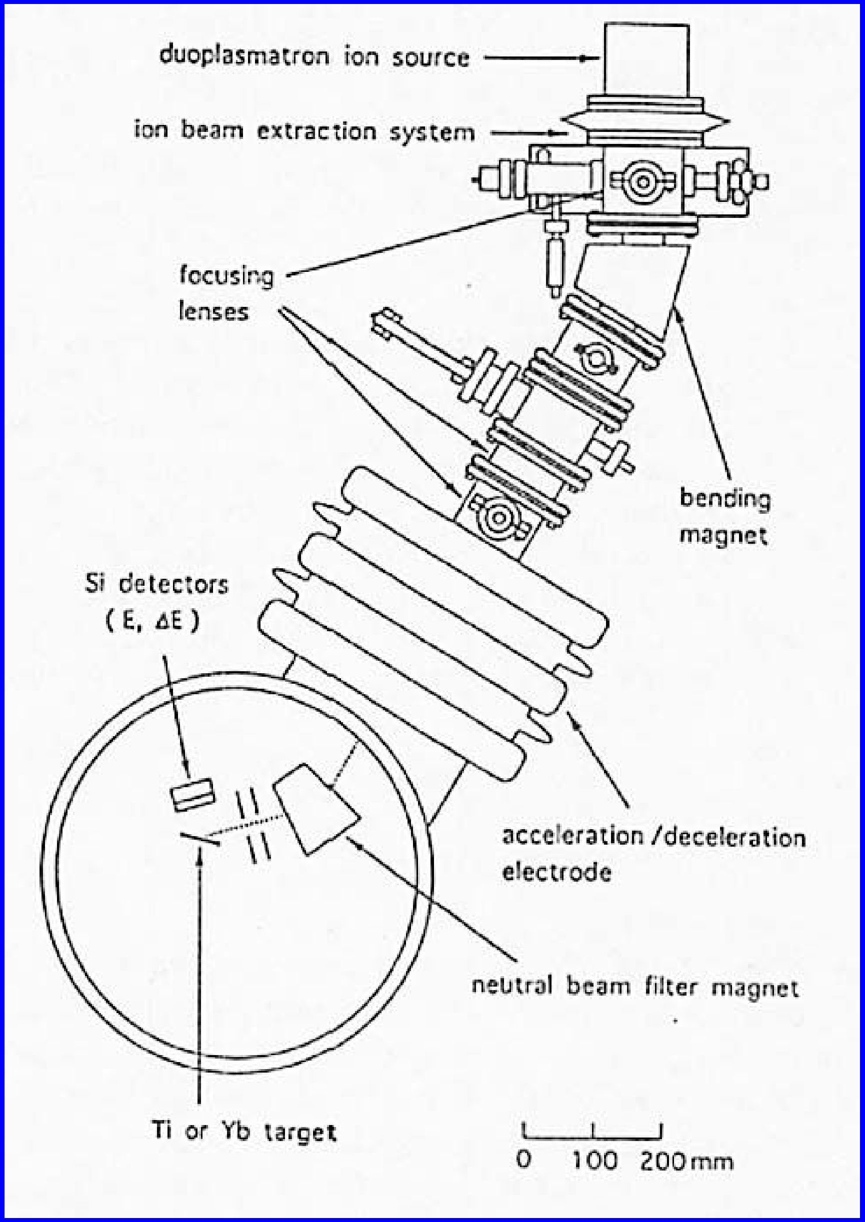
Target deuterium atoms implanted into metals *are no longer in* ***s****-state*. The free electron cloud in a metal causes the electron of an implanted atom to occupy the excited ***p***-state. The magnitude of the screening potential of ***300 eV*** and above in experiments on DD-fusion accelerators indicates that the incident deuterium atoms in the conductor crystal are also moving in ***p***-state.

These processes allow the two deuterium nuclei to get close without the Coulomb repulsion in the potential niche of the crystal cell at a very close distance.

One of the first DD experiments on accelerators.

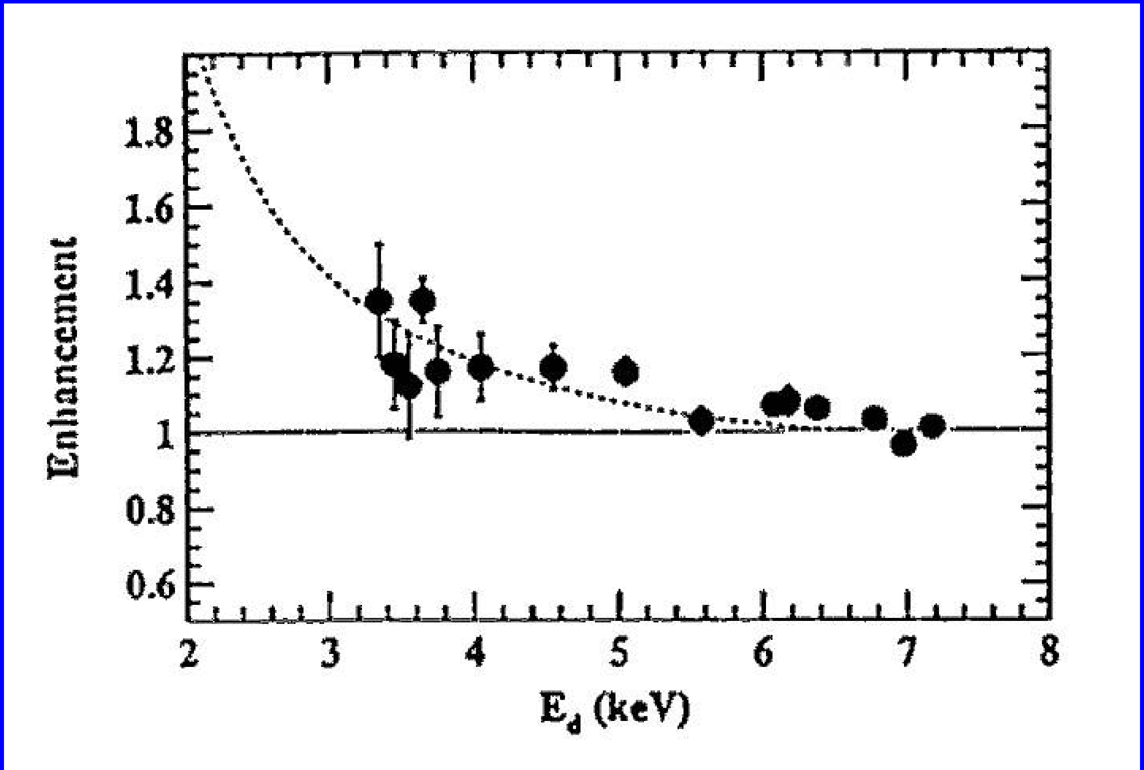
Yuki, H., Satoh, T., Ohtsuki, T., Yorita, T., Aoki, Y., Yamazaki, H., Kasagi, J. (1996).

ICCF-6, 13–18 October, Japan.



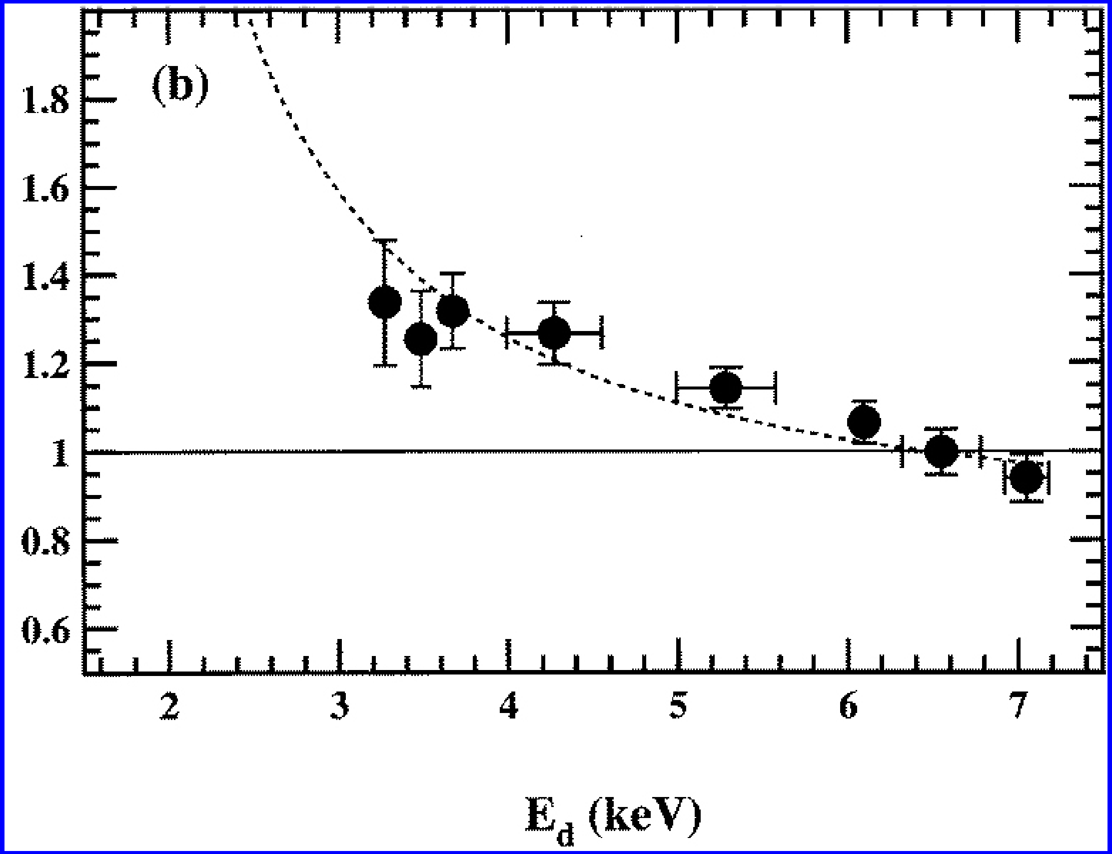
Yuki, H., Satoh, T., Ohtsuki, T., Yorita, T., Aoki, Y., Yamazaki, H., Kasagi, J. (1996). ICCF-6, 13–18 October, Japan.

This is one of the early works on electron screening in metals.



Ratio of the yield of the reaction D(d, p)T in the thick target to the estimated yield value in ytterbium (Yb). The dashed line shows the value of electron screening potential of 60 eV.

Yuki, H., Satoh, T., Ohtsuki, T., Yorita, T., Aoki, Y., Yamazaki, H., Kasagi, J. (1997). Phys. G: Nucl. Part. Phys., 23, 1,459–1,464. Increasing cross-section in ytterbium (rare earth element with a metallic conductivity)—electron screening potential reaches 81 ± 10 eV.

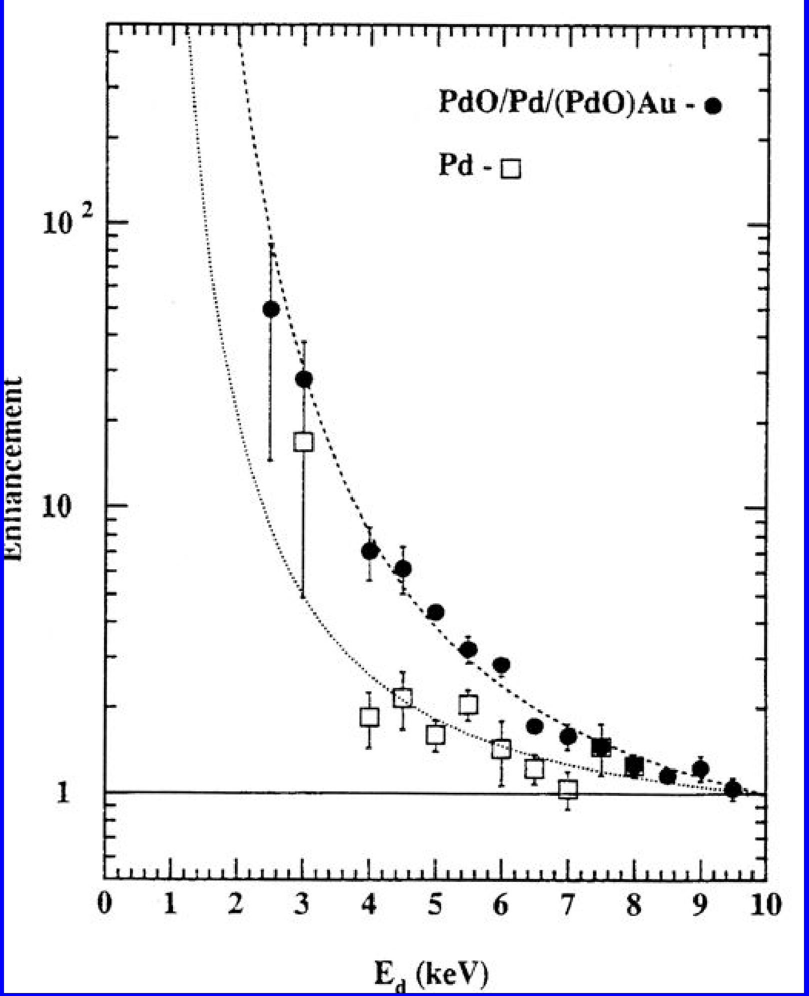


The Seventh International Conference on Cold Fusion. 1998. Vancouver, Canada:, ENECO, Inc., Salt Lake City, UT. p. 180.

"Anomalously enhanced d(d,p)t reaction in Pd and PdO observed at very low bombarding energies"

J. Kasagi, H. Yuki, T. Itoh, N. Kasajima, T. Ohtsuki and A. G. Lipson *

Laboratory of Nuclear Science, Tohoku University, Japan
* Institute of Physical Chemistry, The Russian Academy of Sciences, Moscow, Russia



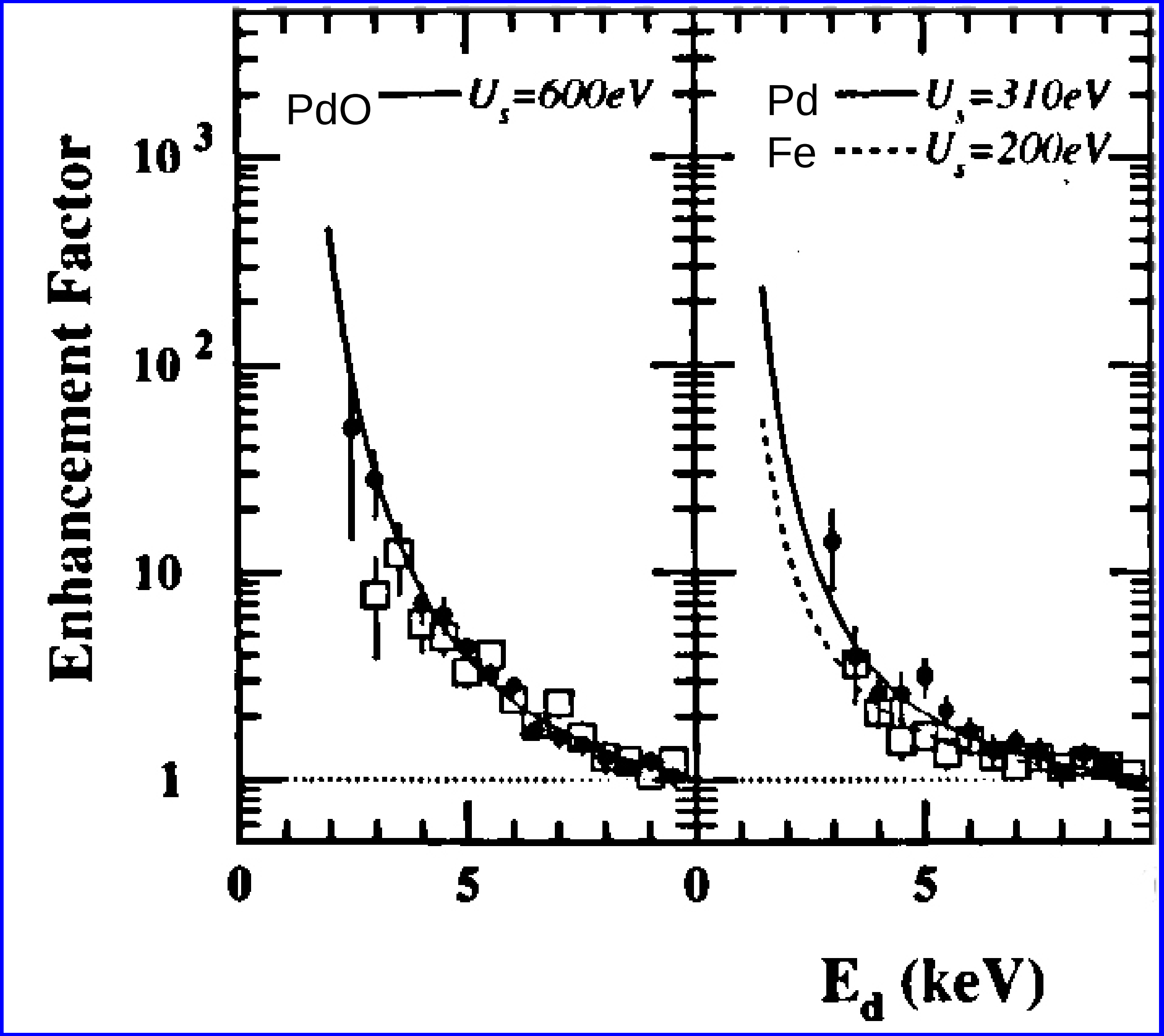
The dotted and dashed curves are those with the screening potential *Ue* = 250 and 600 eV, respectively.

One of the latest (2002) Japanese DD accelerator experiments.

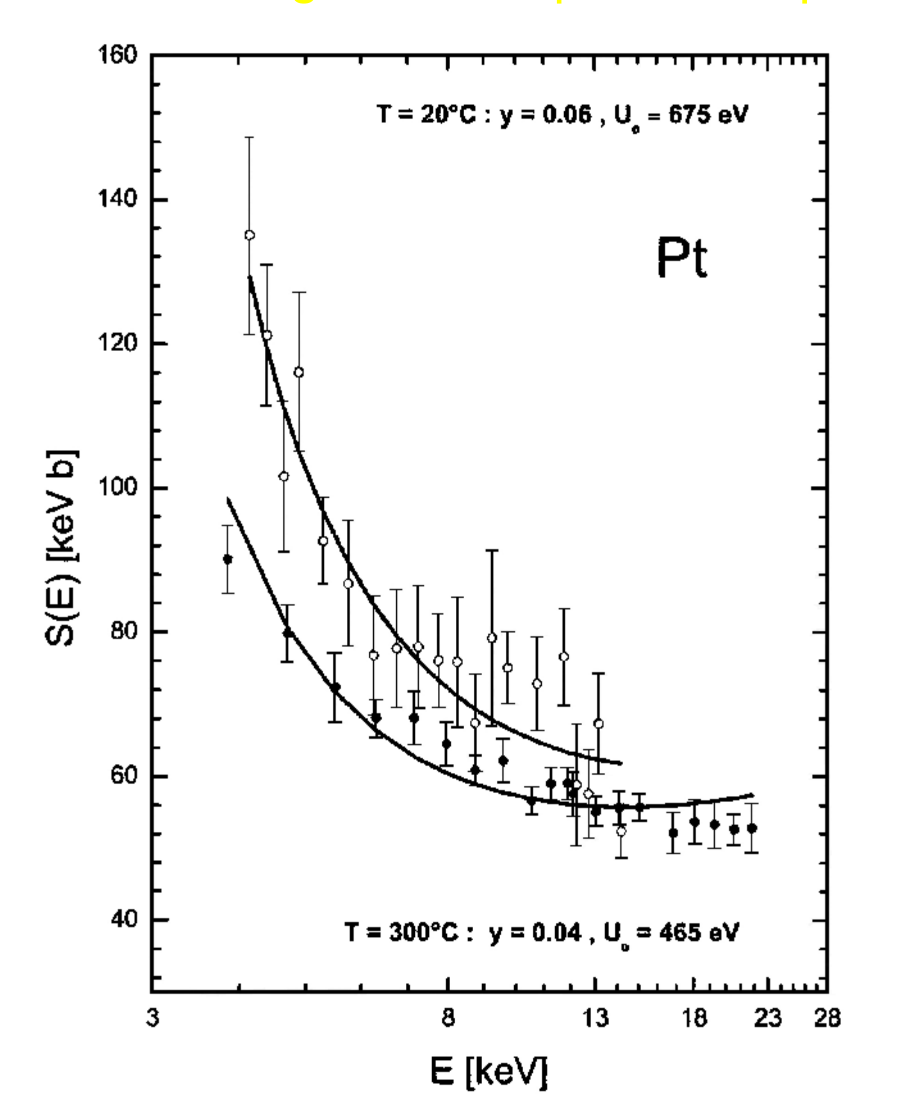
Jirohta Kasagi, Hideyuki Yuki, Taiji Baba, Takashi Noda, Tsutomu Ohtsuki and Andrey G. Lipson

"Strongly Enhanced DD Fusion Reaction in Metals Observed for keV D+ Bombardment"

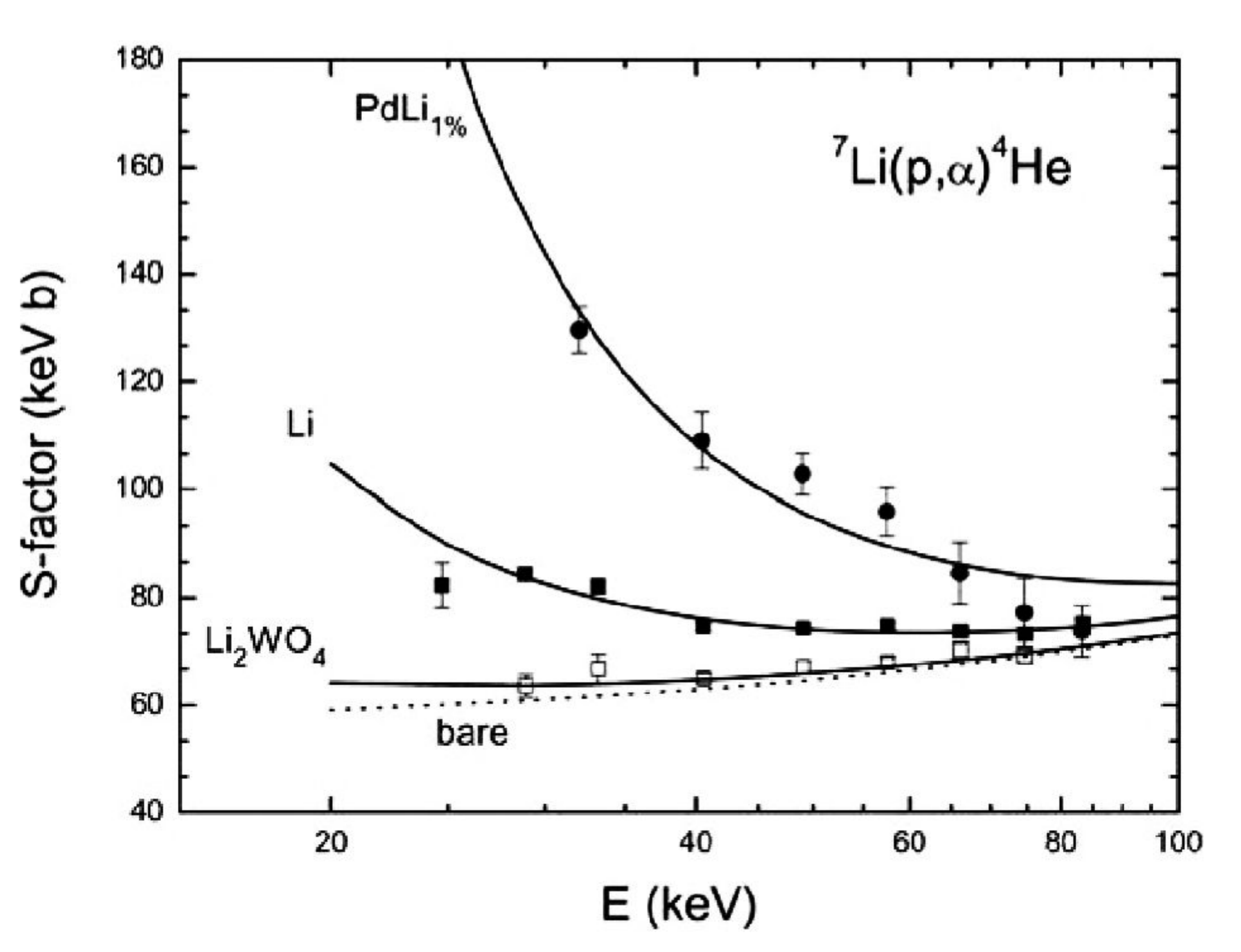
Journal of the Physical Society of Japan, Vol. 71, No. 12, December, 2002, pp. 2881-2885.



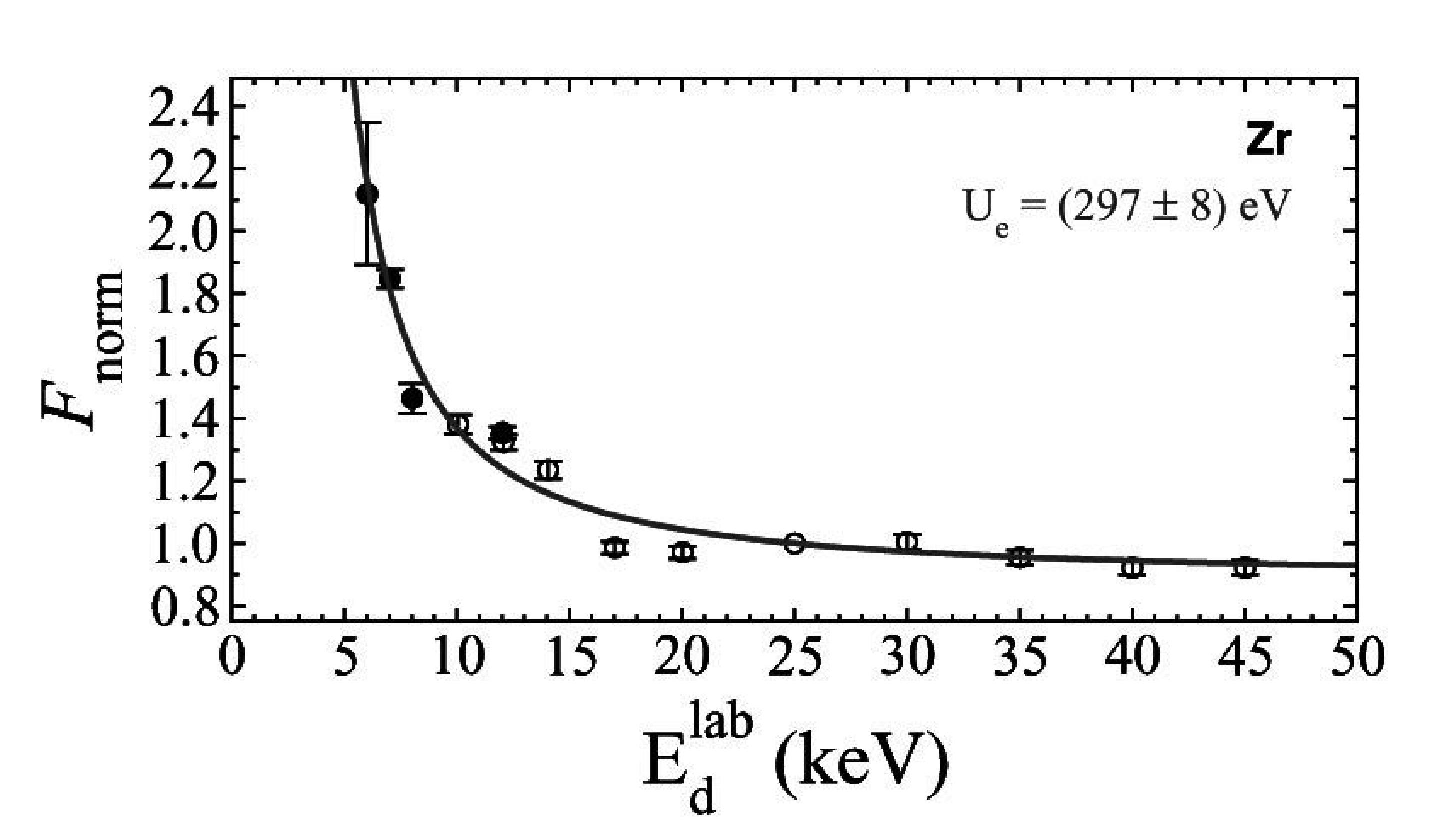
Rolfs, C. et al. (2005). J. Phys. G: Nucl. Part. Phys., 31, 1,141–1,149. (Gran Sasso). S(E) for DD-fusion, targets are implanted in platinum, Ue = 675 eV.



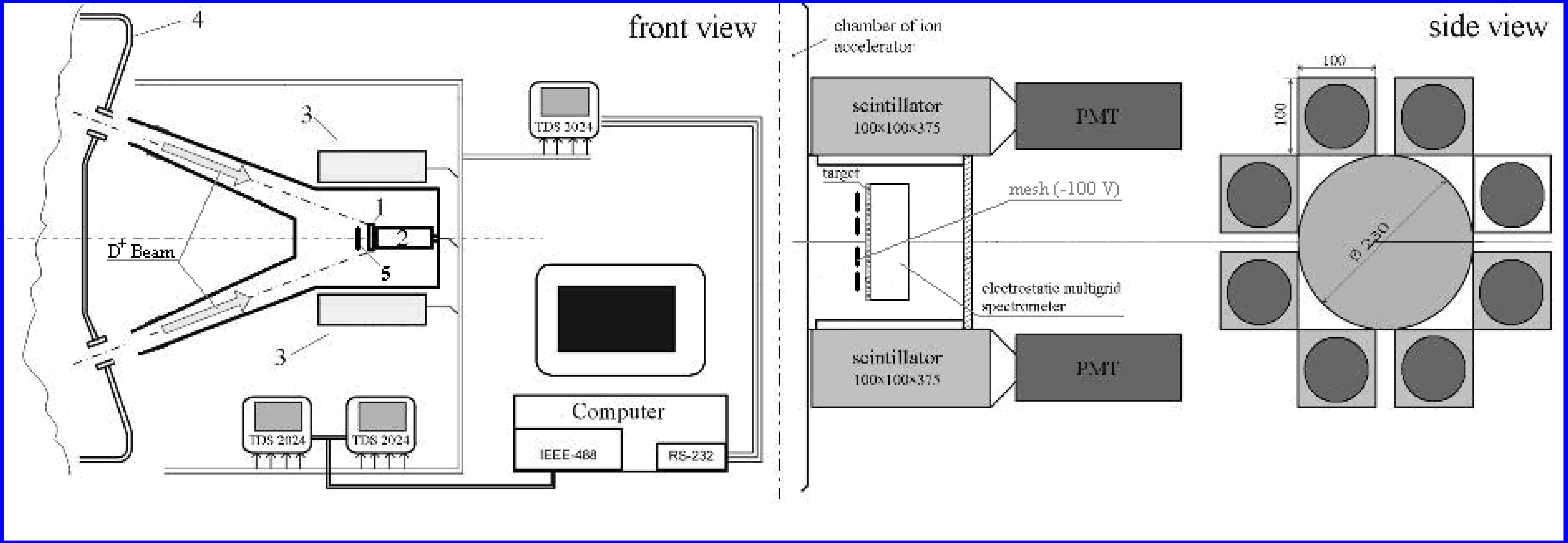
Rolfs, C. (2006). Nuclear Physics News, 16(2), 9. Normalized astrophysical factor *S(E)* for the synthesis of *p+7Li* when a target *7Li* implanted into palladium.



Czerski, K. et al., (2008). Physical Review C., 78, 015803, (Berlin). Normalized astrophysical factor *S(E)* for DD-fusion, when the target is implanted in zirconium. Screening potential is about 10 times greater than for the free atoms of deuterium.

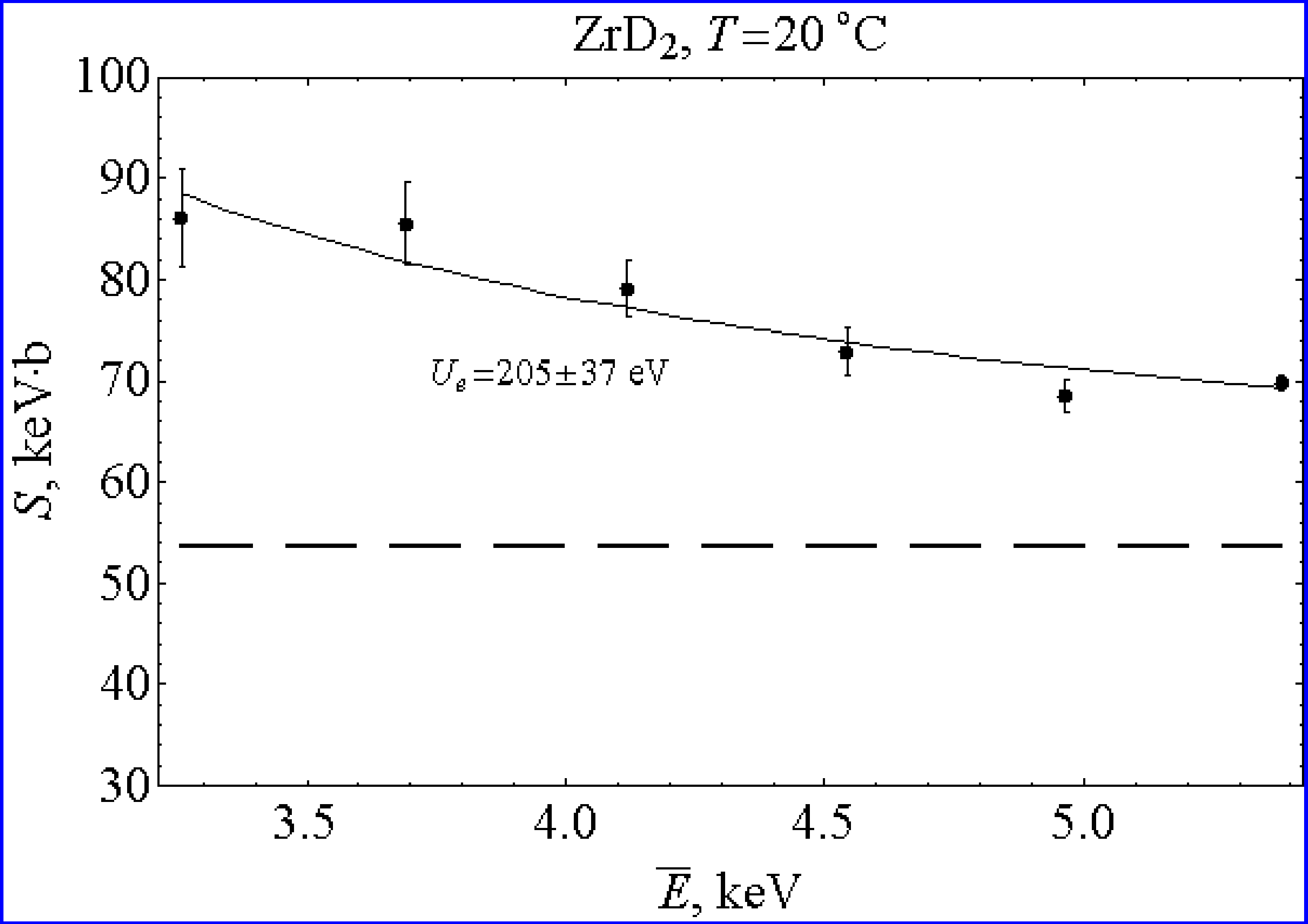


V. M. Bystritsky, Vit. M. Bystritskii, G. N. Dudkin, M. Filipowicz, S. Gazi, J. Huran, A. P. Kobzev, G. A. Mesyats, B. A. Nechaev, V. N. Padalko, S. S. Parzhitskii, F. M. Pen'kov, A. V. Philippov, V. L. Kaminskii, Yu. Zh. Tuleushev, J. Wozniak et al. (2012). National Scientific Research—Tomsk Polytechnical University, Russia, Nuclear Physics, A 889, 93–104.



Bystritsky, V. M. et al., National Scientific Research—Tomsk Polytechnical University, Russia.

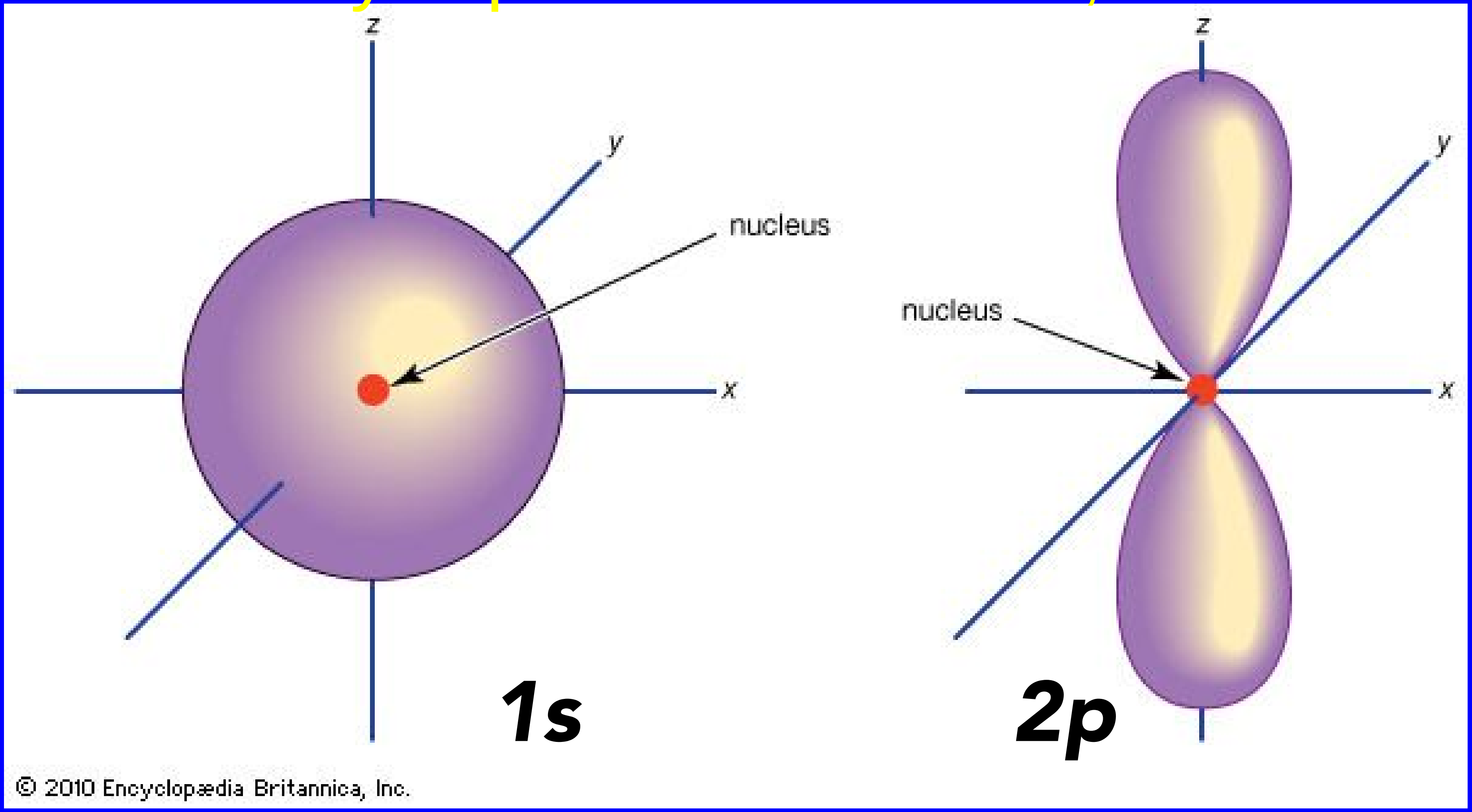
Nuclear Physics, A 889 (2012) 93–104.



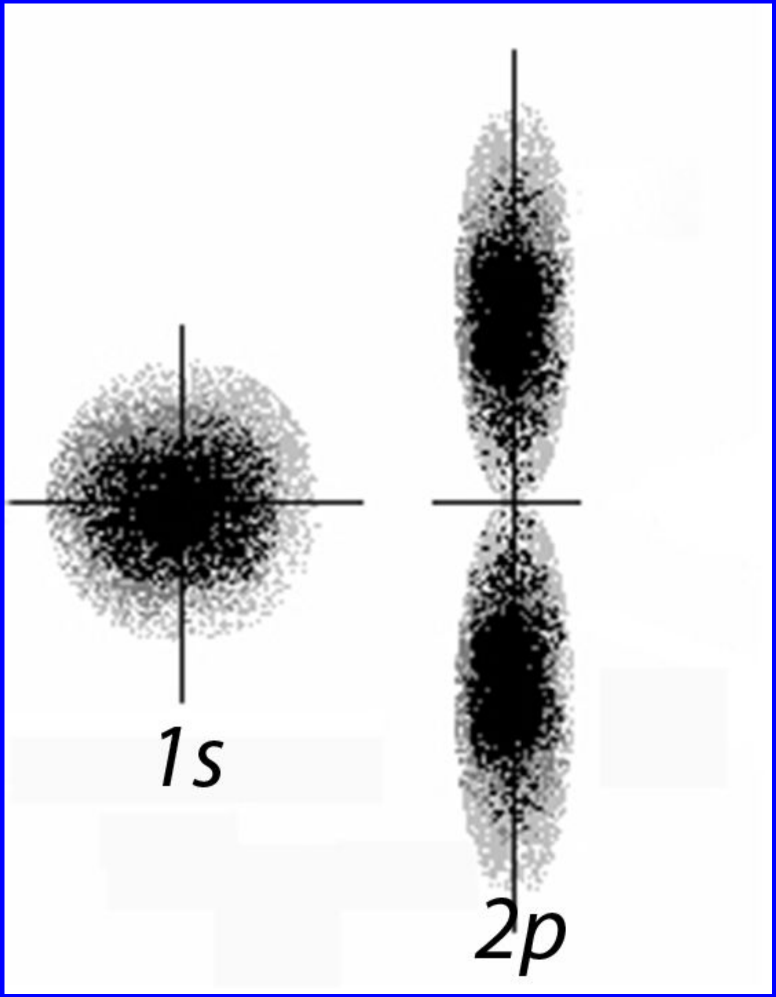
Thus, the convergence distance of two deuterium nuclei of impurity caught in the same crystalline niche of metal is an order of magnitude smaller than the size of the free atom of deuterium.

Although complete interpretation of this phenomenon is still lacking, many accelerator experiments leave no doubt to its existence. Coulomb barrier permeability in such conditions during the cold DD-fusion is very strongly (55–60 orders) increased as compared to the permeability of the barrier in the case of the free molecule of deuterium.

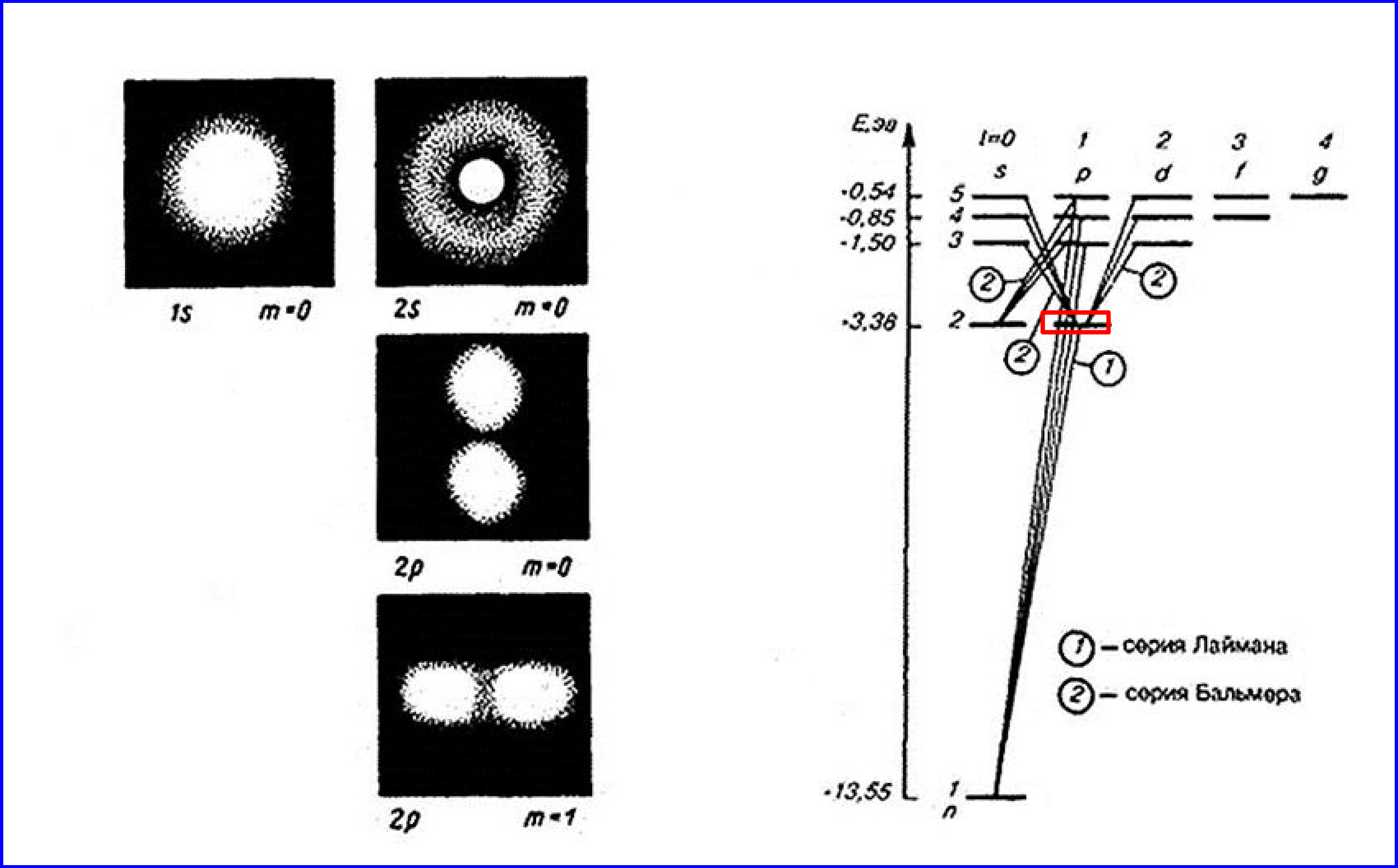
Orbitals of the hydrogen atom
Encyclopædia Britannica, 2010



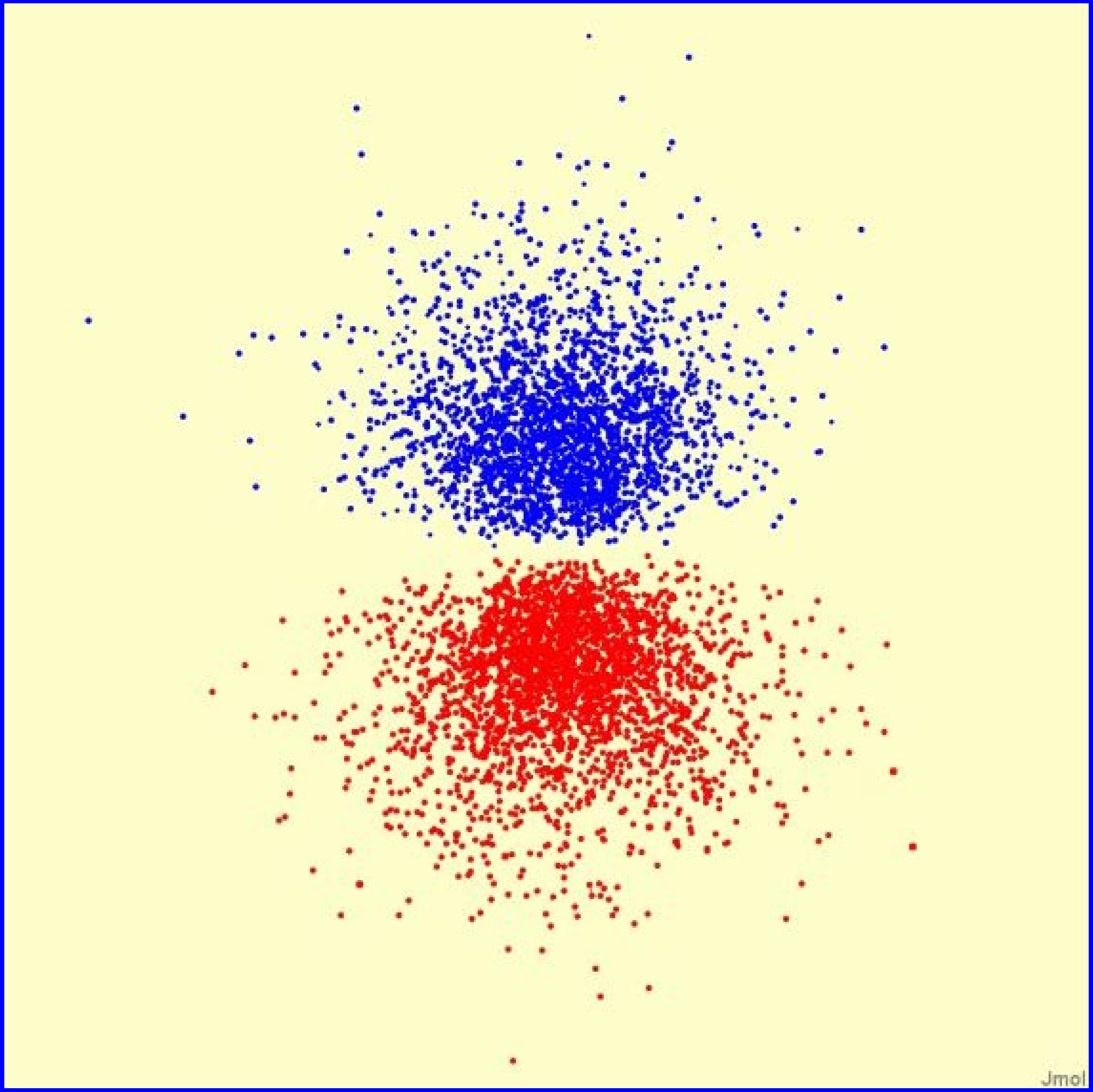
Orbitals of the hydrogen atom



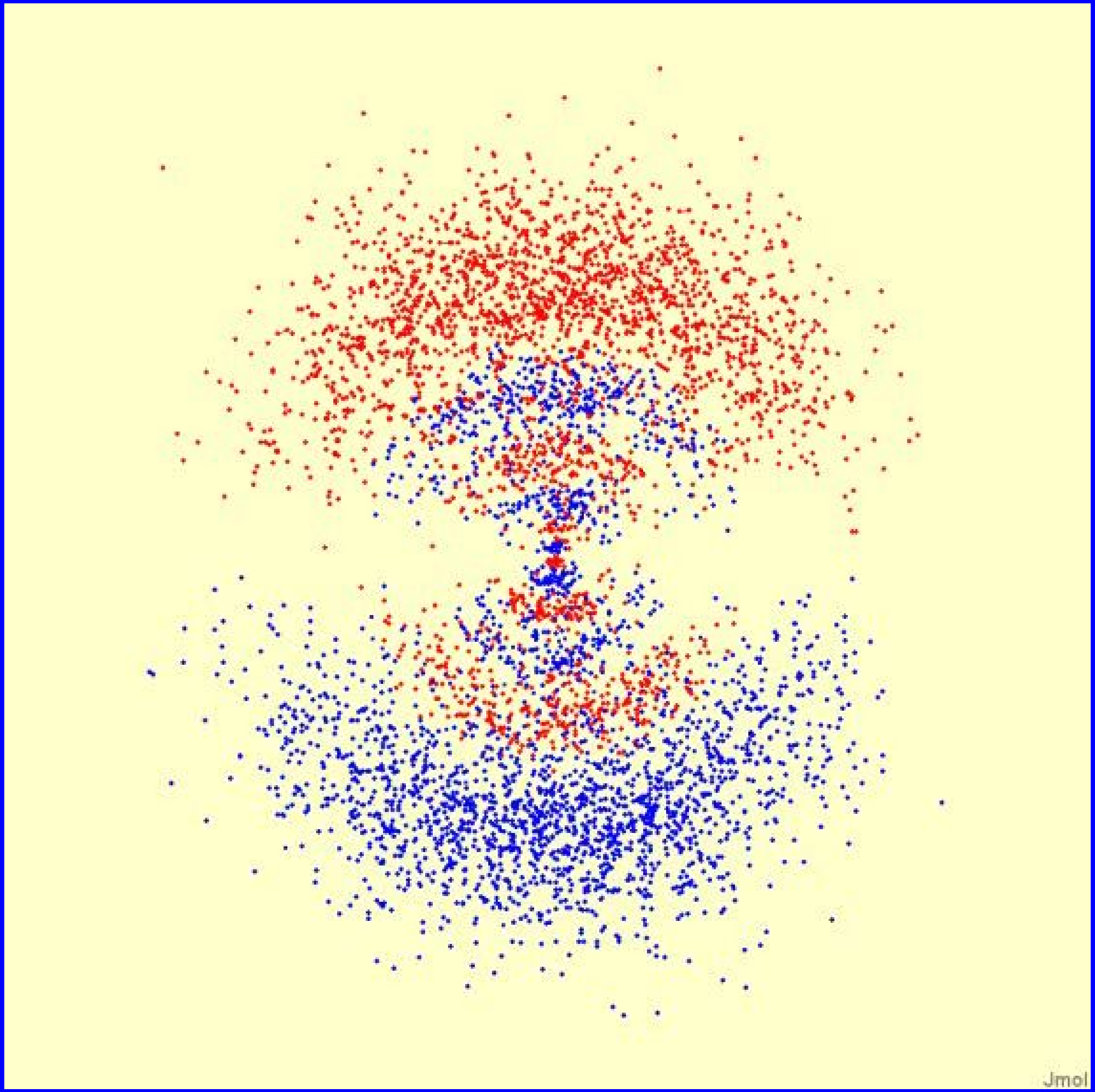
Rydberg mechanism for the hydrogen atom. Electron orbital in 2p-state is no longer circular.



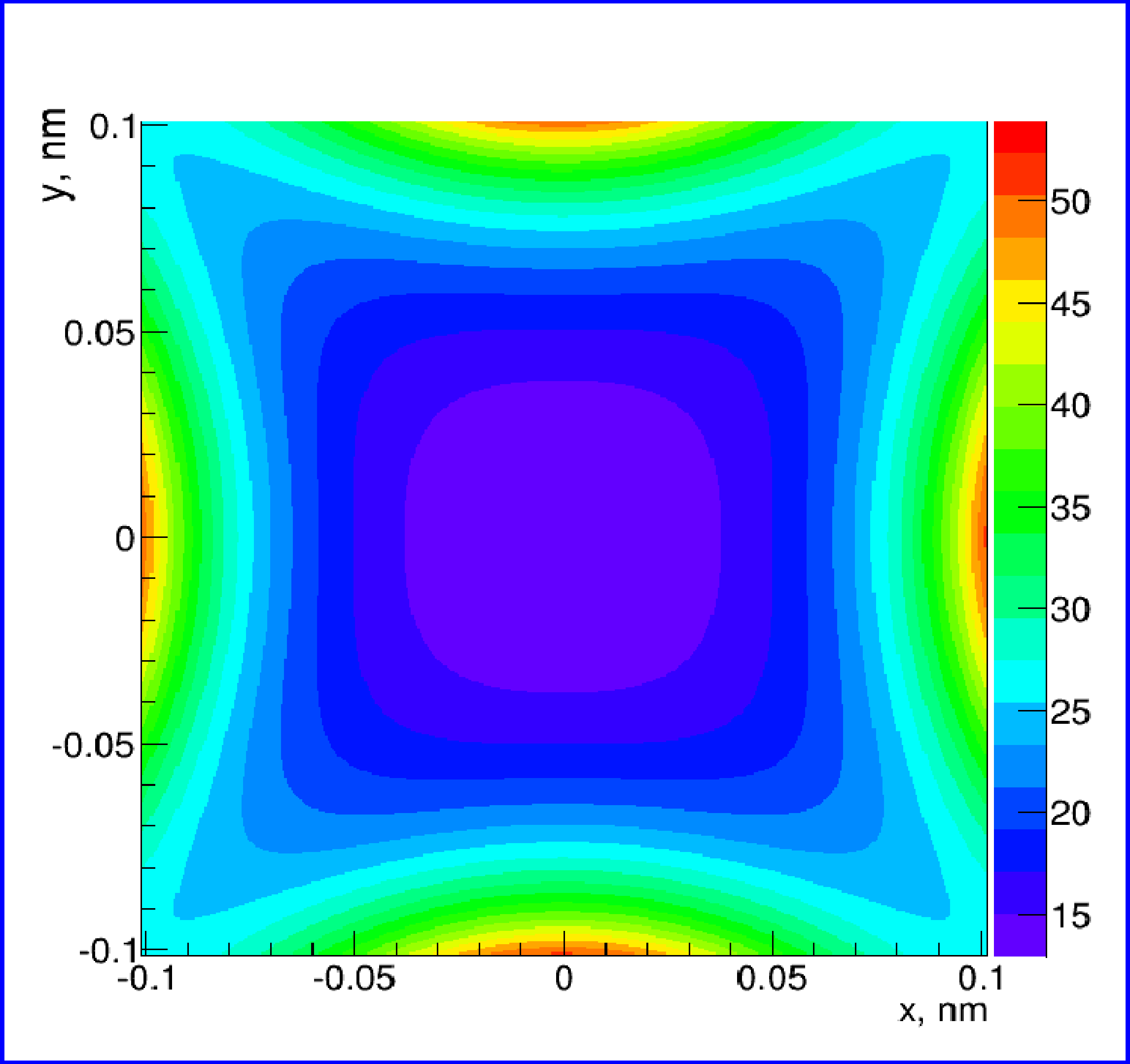
2p orbital of the hydrogen atom by Dr. Winter



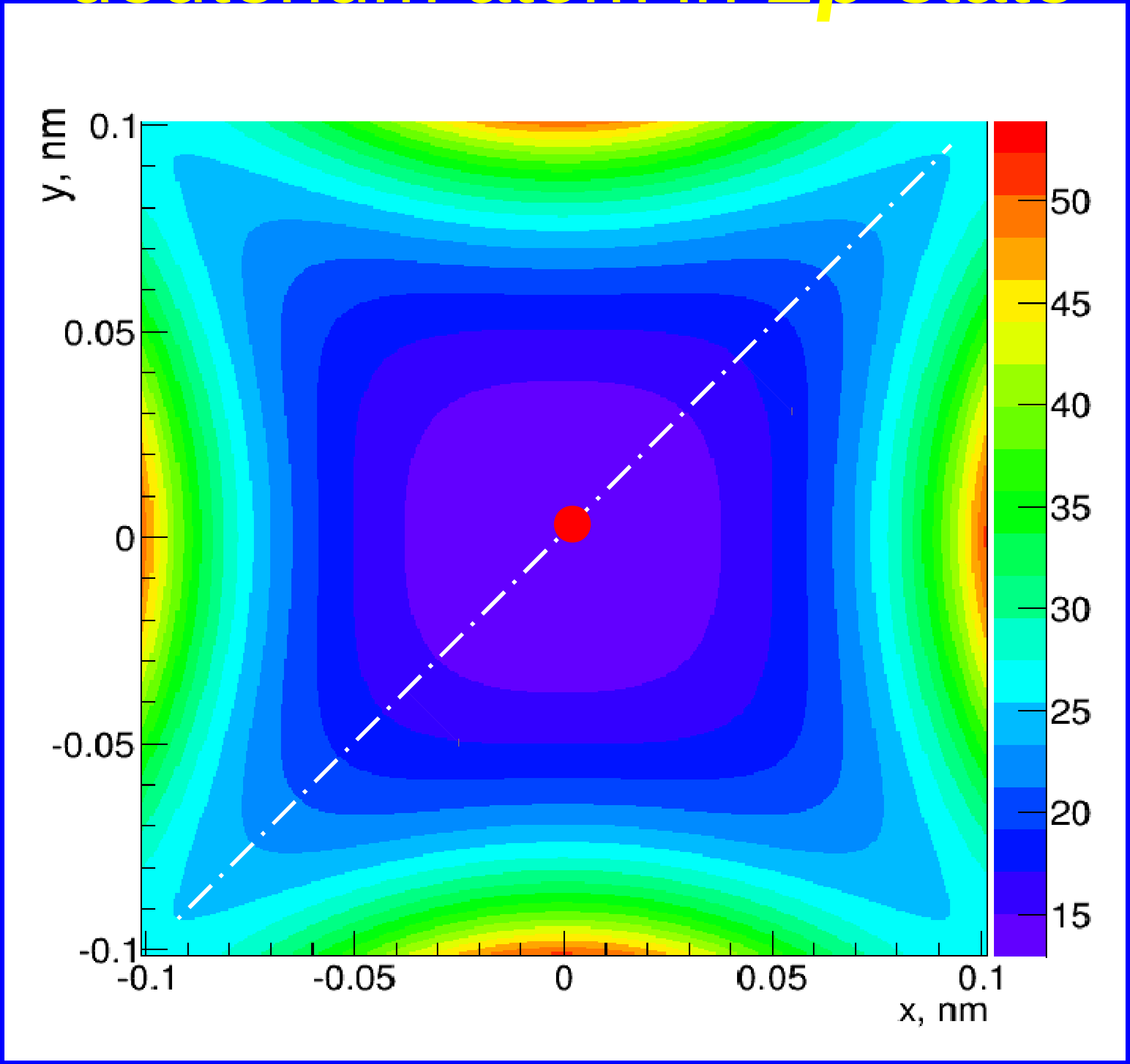
7p orbital of the hydrogen atom by Dr. Winter



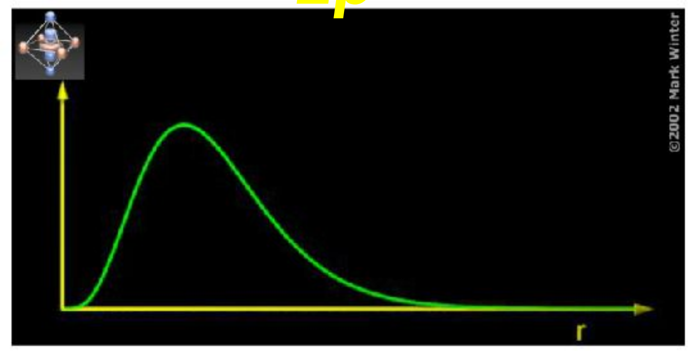
Structure of octahedral niche in platinum crystal.



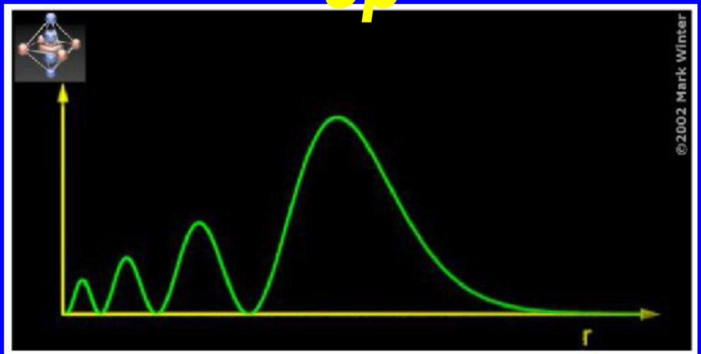
Octahedral platinum crystal niche filled with a deuterium atom in *2p*-state



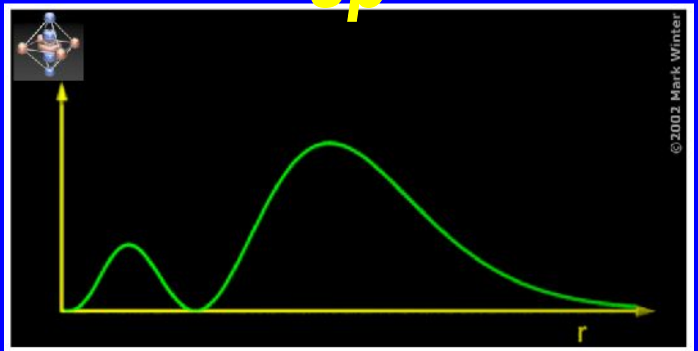
2p



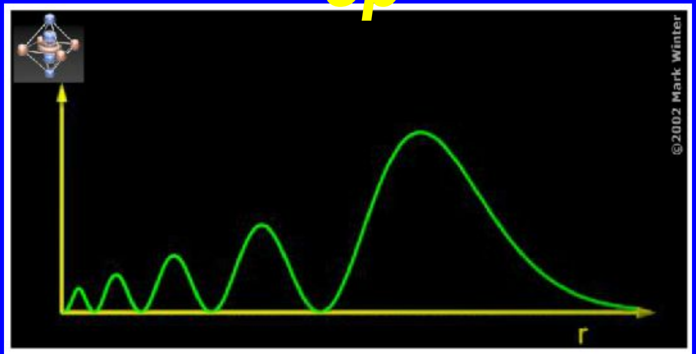
5p



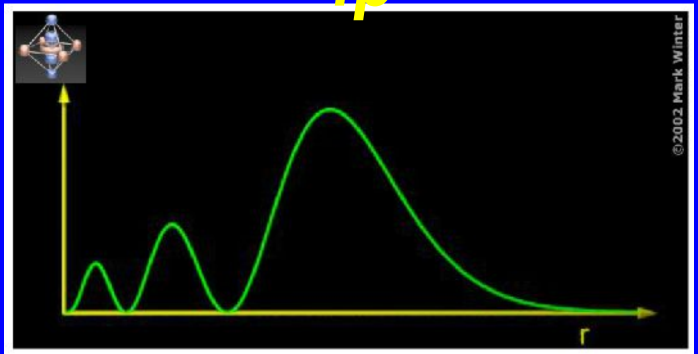
3p



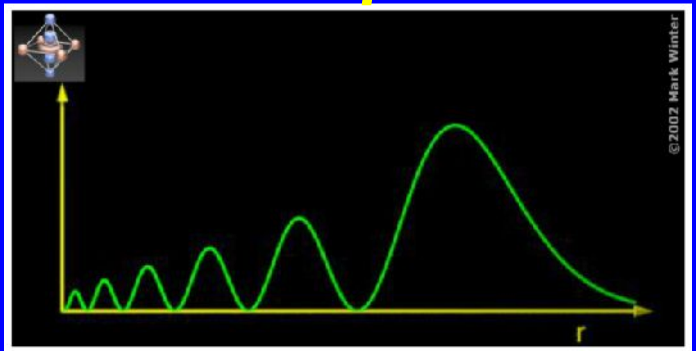
6p



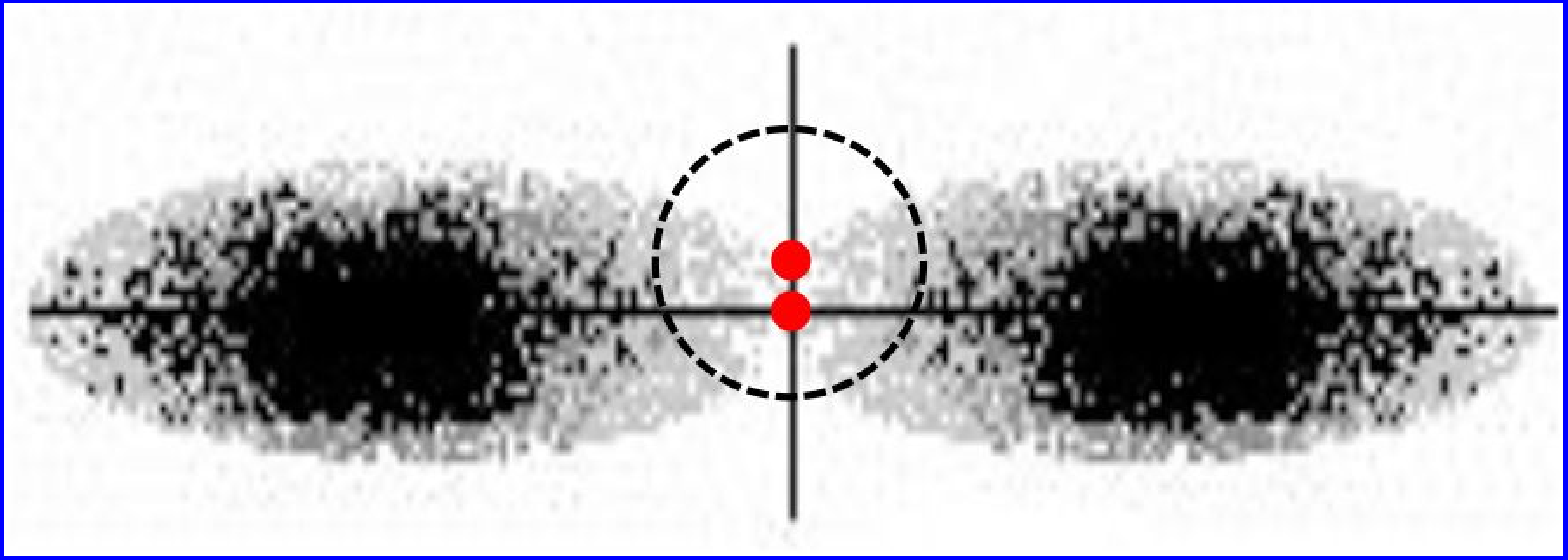
4p



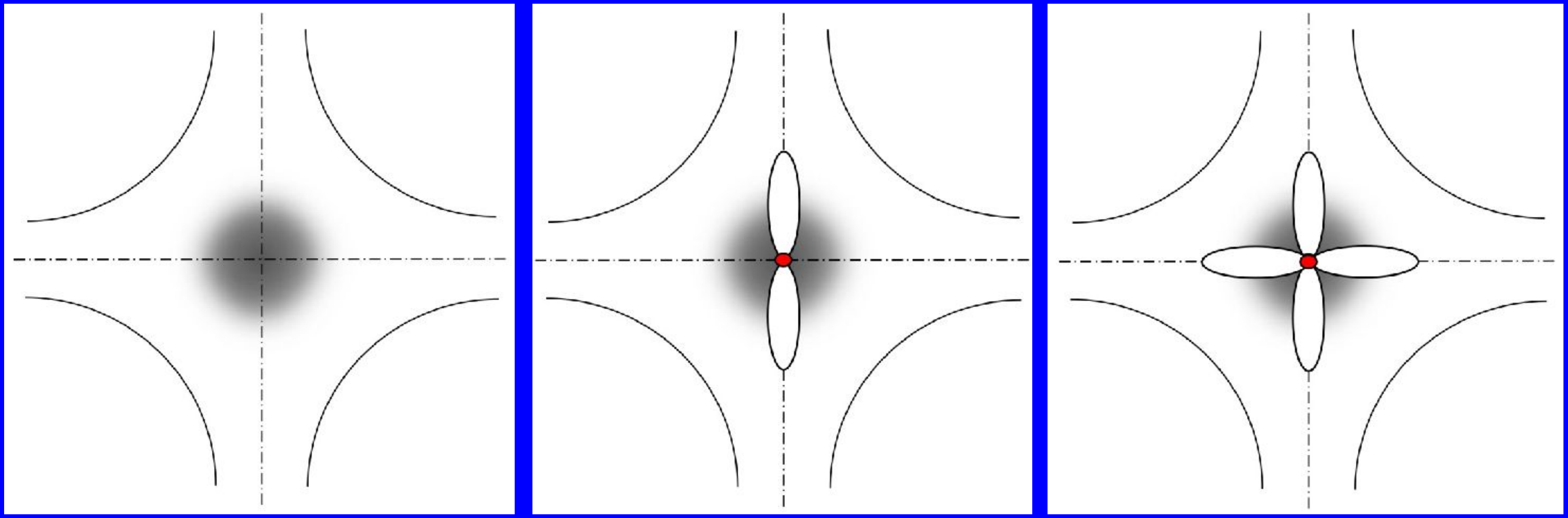
7p



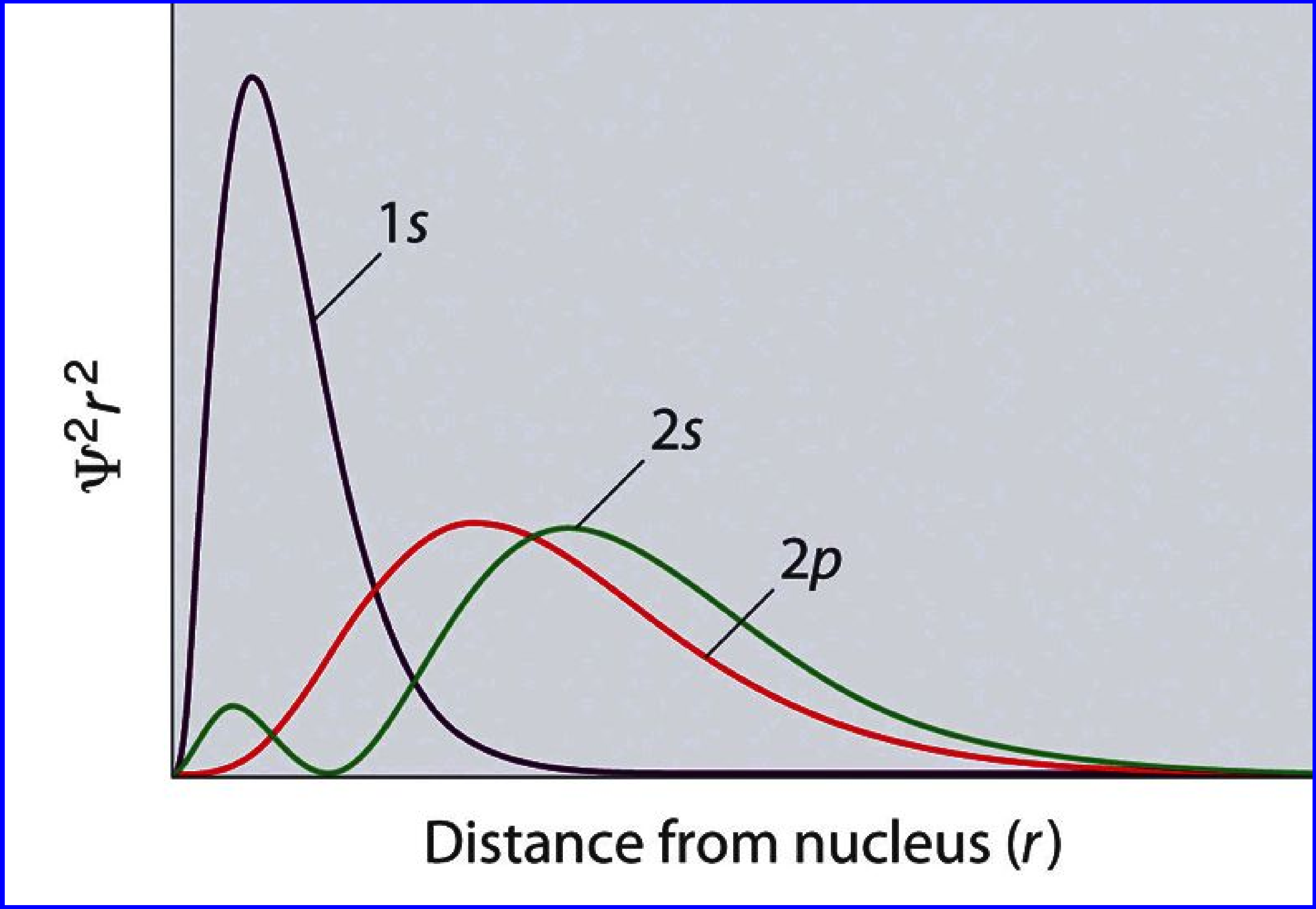
The case when two atoms of deuterium in ***2p***-state are located in the same octahedral niche of conducting crystal.



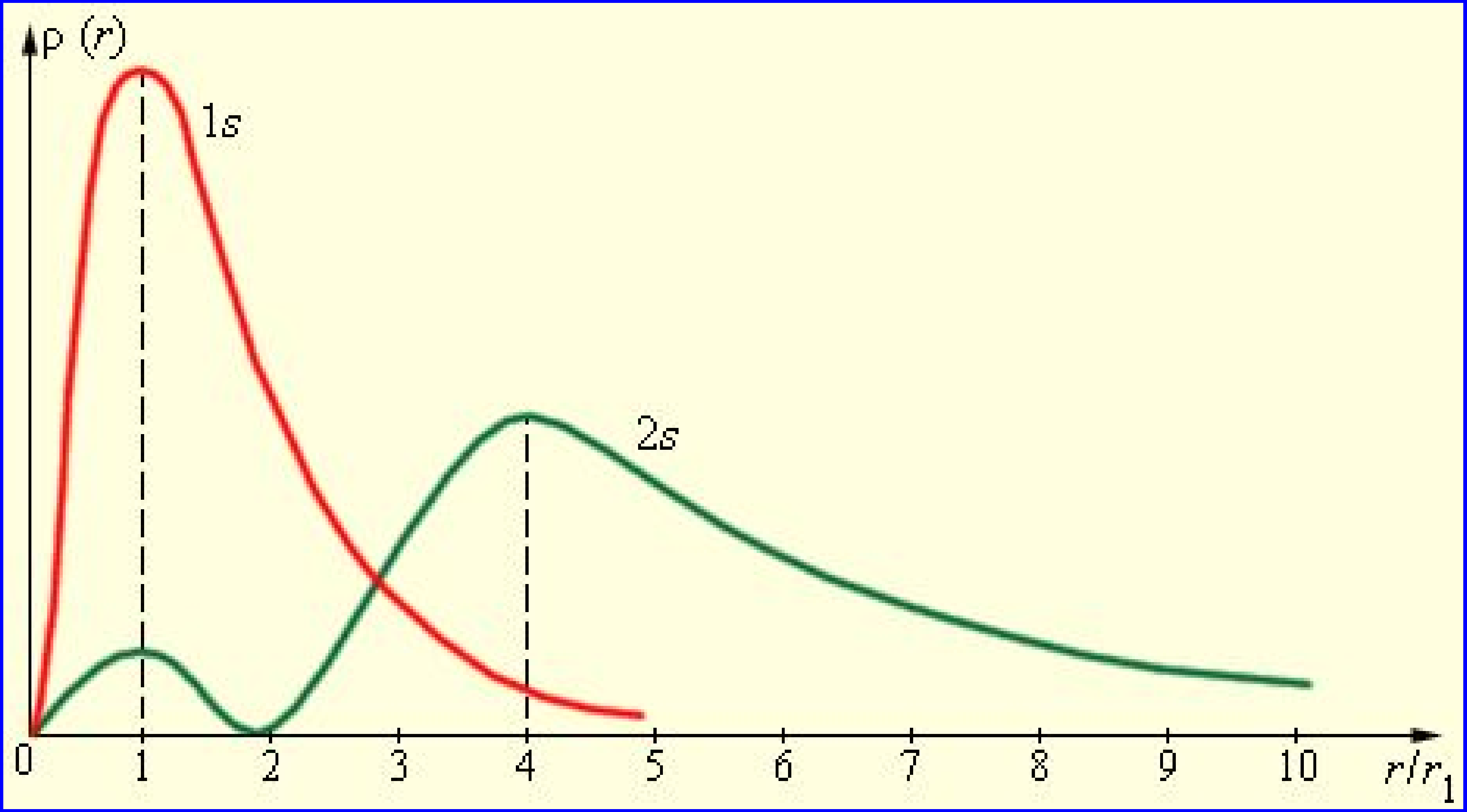
Crystal cells of conductor. The simple, cubic structure is used as a didactic example. The shaded area shows the location of free electrons. Free electrons of conducting crystal are unwilling to vacate their positions completely, and the deuterium atom is transferred from ***1s***-state to ***2p***-state or higher.



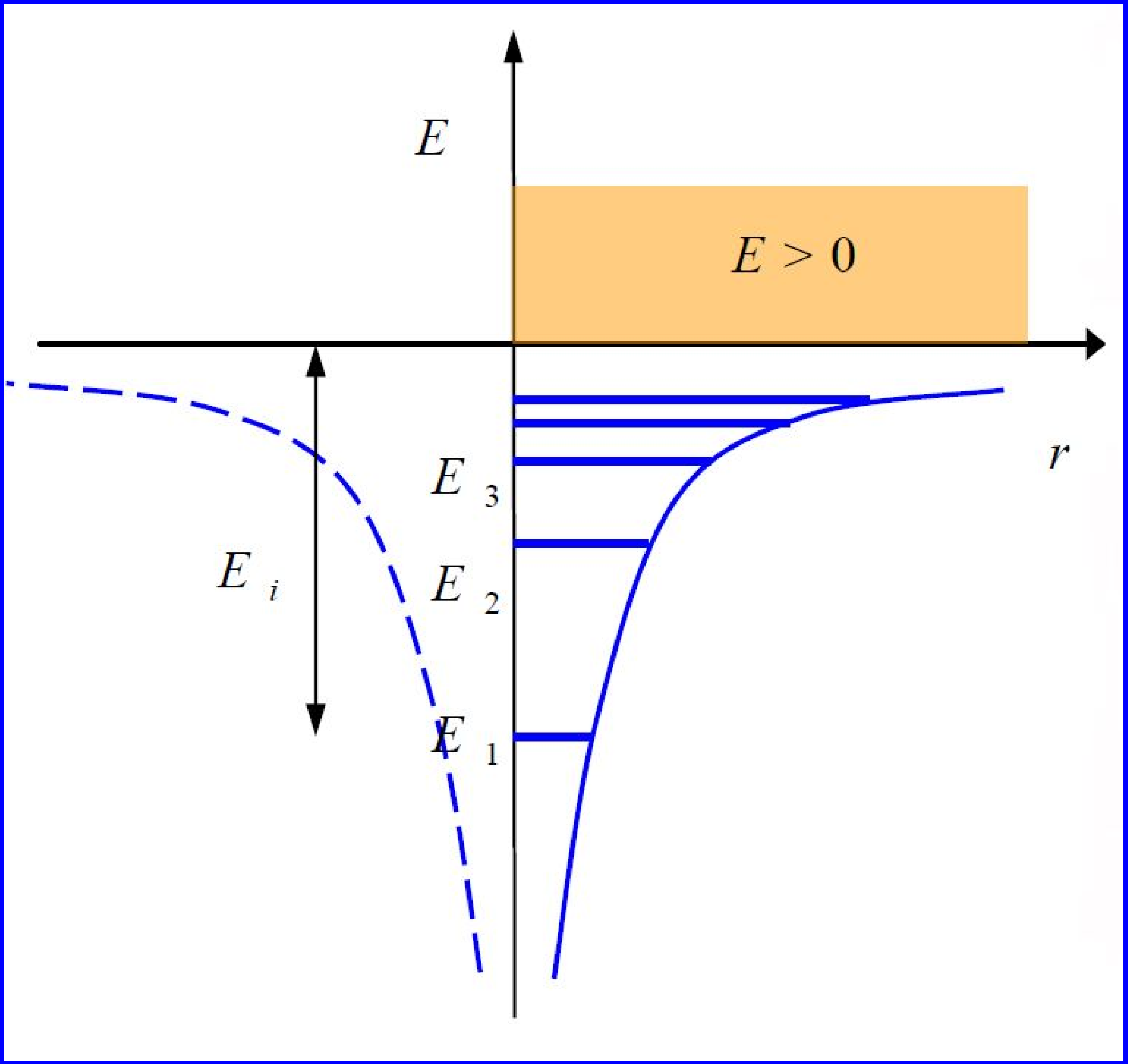
***1s*, *2s* and *2p* orbitals of hydrogen atoms**



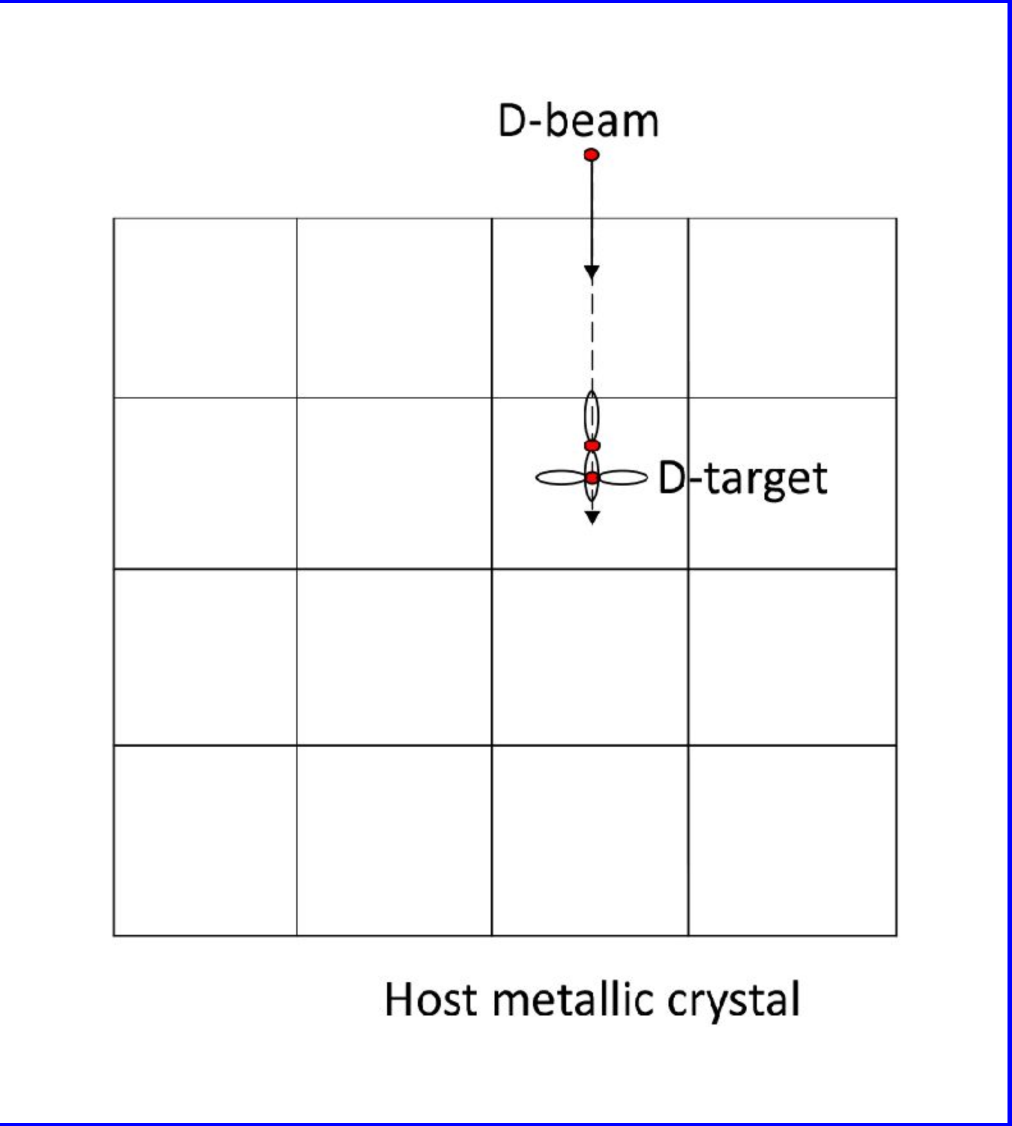
1s and ***2s*** orbitals of hydrogen atom



Schrödinger equation for hydrogen atom



Accelerator experiments



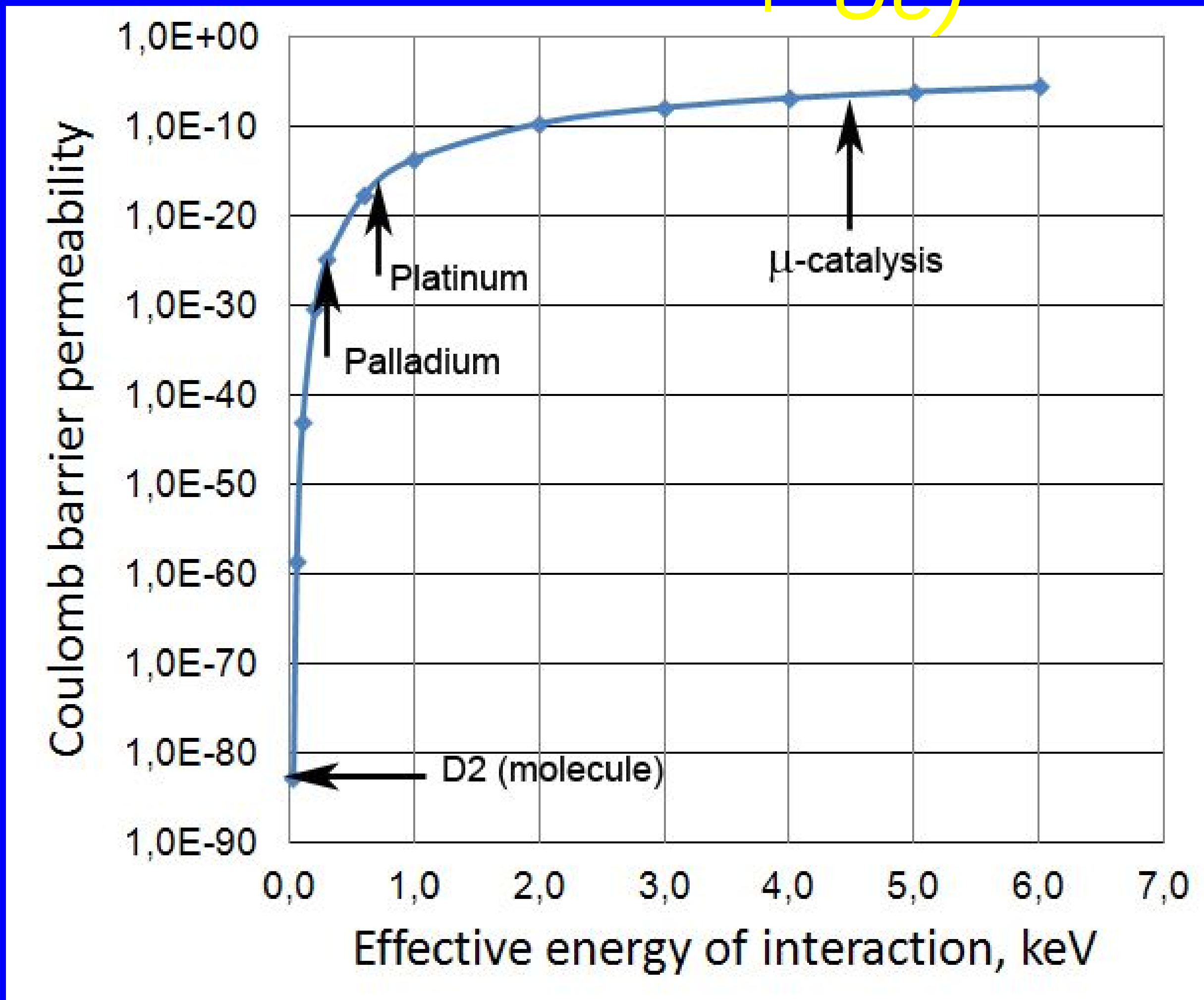
Cross section of synthesis in the collision of two deuterium nuclei:

$$\sigma(E) = S(E)\, E{-1}\, \exp(-2\pi\eta(E))$$
$$2\pi\eta = 31.41/E^{1/2}$$

Here, the kinetic energy of the deuteron *E* is shown in the center of mass in keV. *S(E)* — astrophysical factor at low energies; it can be assumed to be constant. The main energy dependence of the cold fusion cross-section is contained in the expression $\exp(-2\pi\eta(E))$,
which determines the probability of penetration of the deuteron through the Coulomb barrier in a single collision. In the event of a collision of atoms, the energy *E* must be replaced by $E_{eff} = E + U_e$, where $U_e = e2/Ra$. As we have noted, for the unexcited hydrogen atom, $U_e = 27$ eV.

Coulomb barrier permeability for DD fusion:

$$P = e^{-2\pi\eta} \left(2\pi\eta = 31.41/E_{eff}^{1/2},\ E_{eff} = E + U_e\right)$$



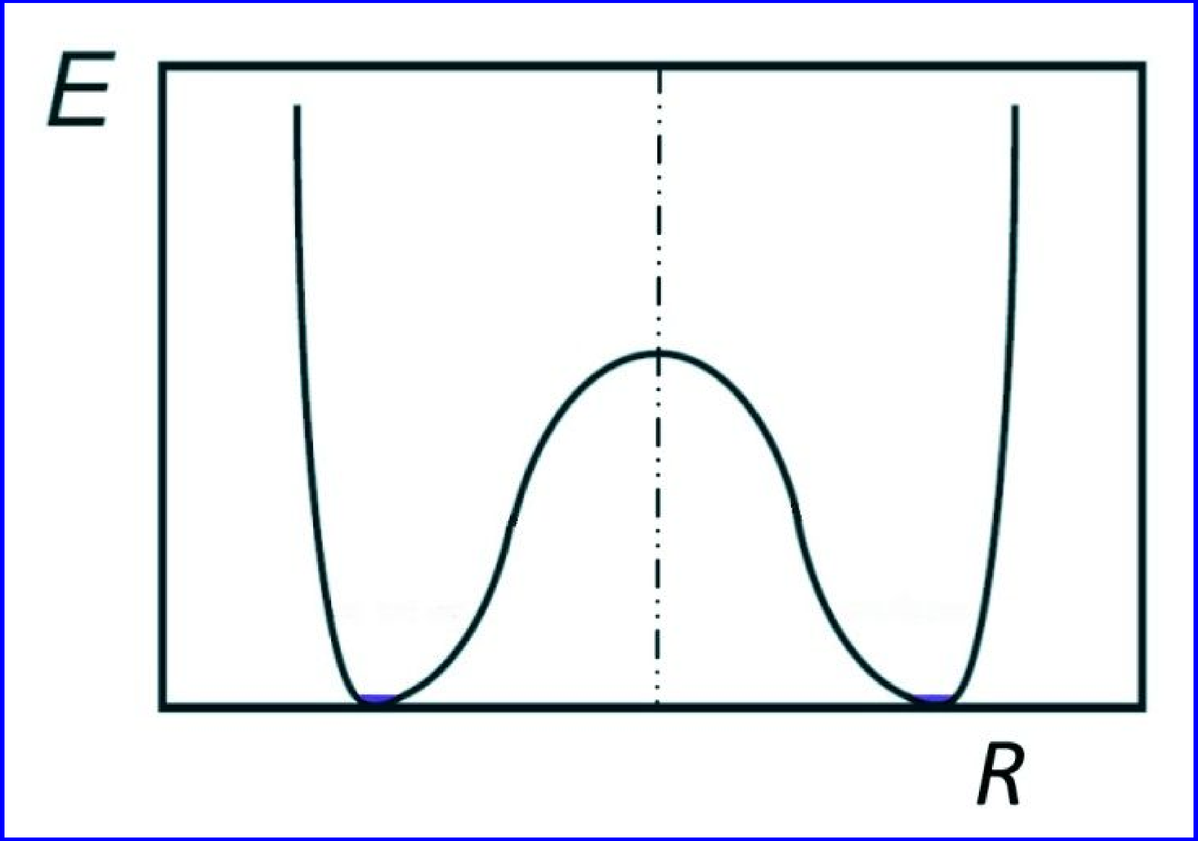
For cold fusion,

E Õ 0.040 eV

So, the first secret of cold fusion, which necessarily results in the fusion of deuterium nuclei at saturation deuterium in conducting crystal, can today be considered practically solved.

The second surprise of the cold fusion process: In these reactions, there are practically no standard nuclear decay products of 4He*.

A possible cause of slowing of nuclear decays with decreasing excitation energy: residual Coulomb barrier between the deuterium nuclei in the potential well of the strong interactions. “Statistical principle of correlation weakening with distance” (*N. N. Bogolubov, Selected works on statistical physics, M., 1979*) may be working for neutrons.



One can assume that the potential inside of the Coulomb barrier common well after the strong interactions of the fusion reaction is no longer a retaining factor for neutrons, and neutrons can almost freely move from one proton to another. In this case, the metastable *DD*-system goes into a metastable *PT*-system.

According to our *hypothesis*, the rate of nuclear decay of a compound nucleus 4He* is a function of the excitation energy of the nucleus *Ek*. We assume that when the *Ek ~ 0* (thermal energy), the compound nucleus 4He* is metastable with a lifetime of about 10-15 s. After a time of ~10-16 seconds, the compound nucleus is no longer an isolated system, since virtual photons from the 4He* can reach the nearest electrons in a crystal, and carry away the excitation energy of the compound nucleus 4He*. It must be emphasized that the above hypothesis is merely an attempt to explain the well-established experimental fact of the virtual absence of nuclear decay channels of the intermediate compound nucleus 4He* in the process of cold fusion.

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NUCLEI
Experiment

Cold Nuclear Fusion*

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Abstract—Recent accelerator experiments on fusion of various elements have clearly demonstrated that the effective cross-sections of these reactions depend on what material the target particle is placed in. In these experiments, there was a significant increase in the probability of interaction when target nuclei are imbedded in a conducting crystal or are a part of it. These experiments open a new perspective on the problem of so-called cold nuclear fusion.

Rate of DD-fusion in the crystal cell

E.N. Tsyganov, *Physics of Atomic Nuclei, 2012, Vol. 75, No. 2, pp. 153–159.*
Э.Н. Цыганов, *ЯДЕРНАЯ ФИЗИКА, 2012, том 75, № 2, с. 174–180.*

In our recent articles, we discuss the possibility of experimental detection of the “cold” DD-fusion using low-energy electrons, which are the result of the fusion reaction of two deuterons in palladium crystals at very low (thermal) excitation energies of the compound nucleus 4He*. This process is made possible by the exchange of the intermediate nucleus with electrons of the crystal lattice by the virtual photons.

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BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Registration of energy discharge in D + D → $^{4}He^{*}$ reaction in conducting crystals (simulation of experiment)

CrossMark

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ABSTRACT

The experiment on registration of low-energy electrons which occur after the fusion reaction of two deuterons in the palladium crystal at very low excitation energies was modeled using Monte Carlo simulations.

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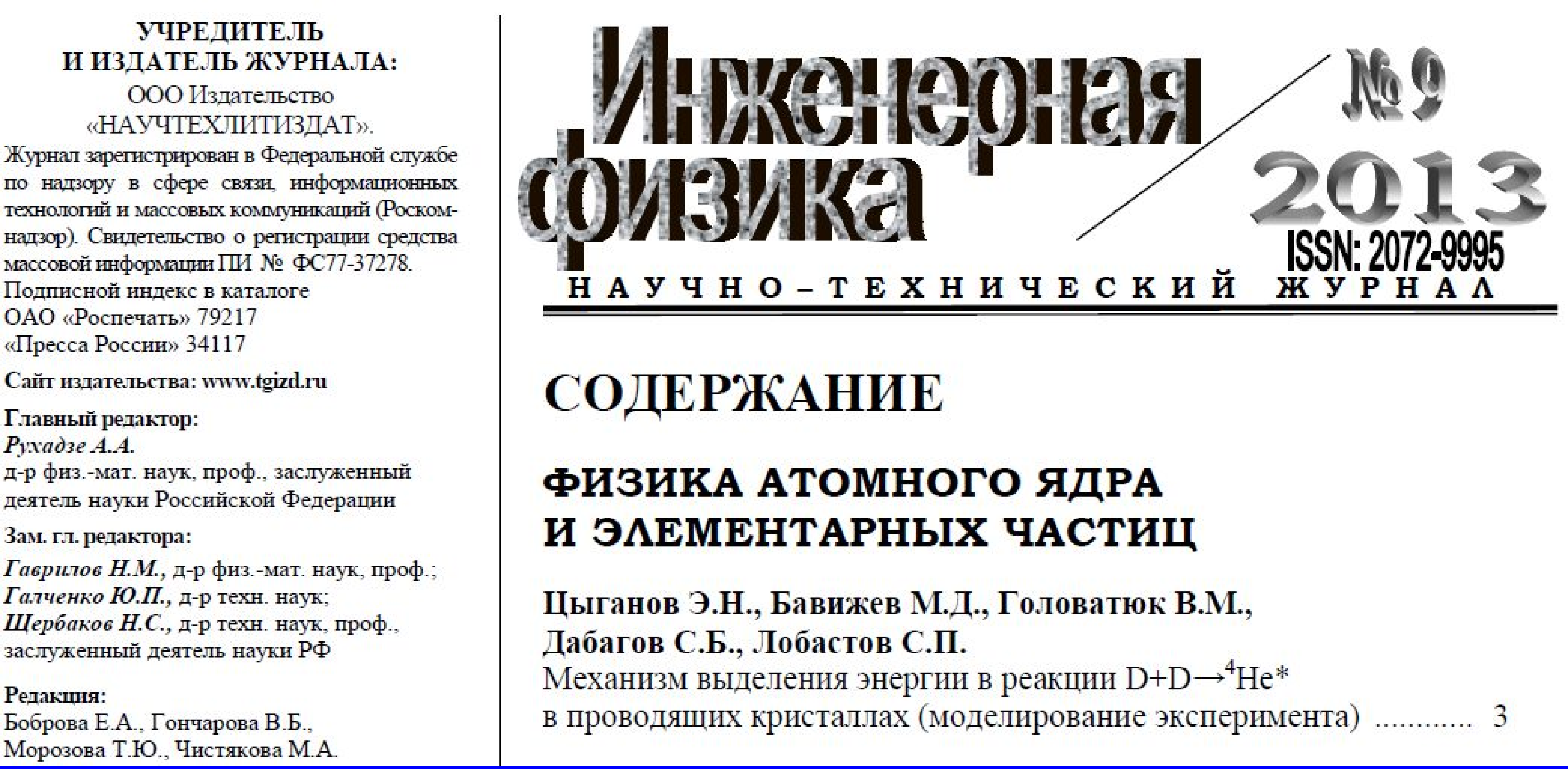

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СОДЕРЖАНИЕ

ФИЗИКА АТОМНОГО ЯДРА И ЭЛЕМЕНТАРНЫХ ЧАСТИЦ

Engineering Physics, June 2014

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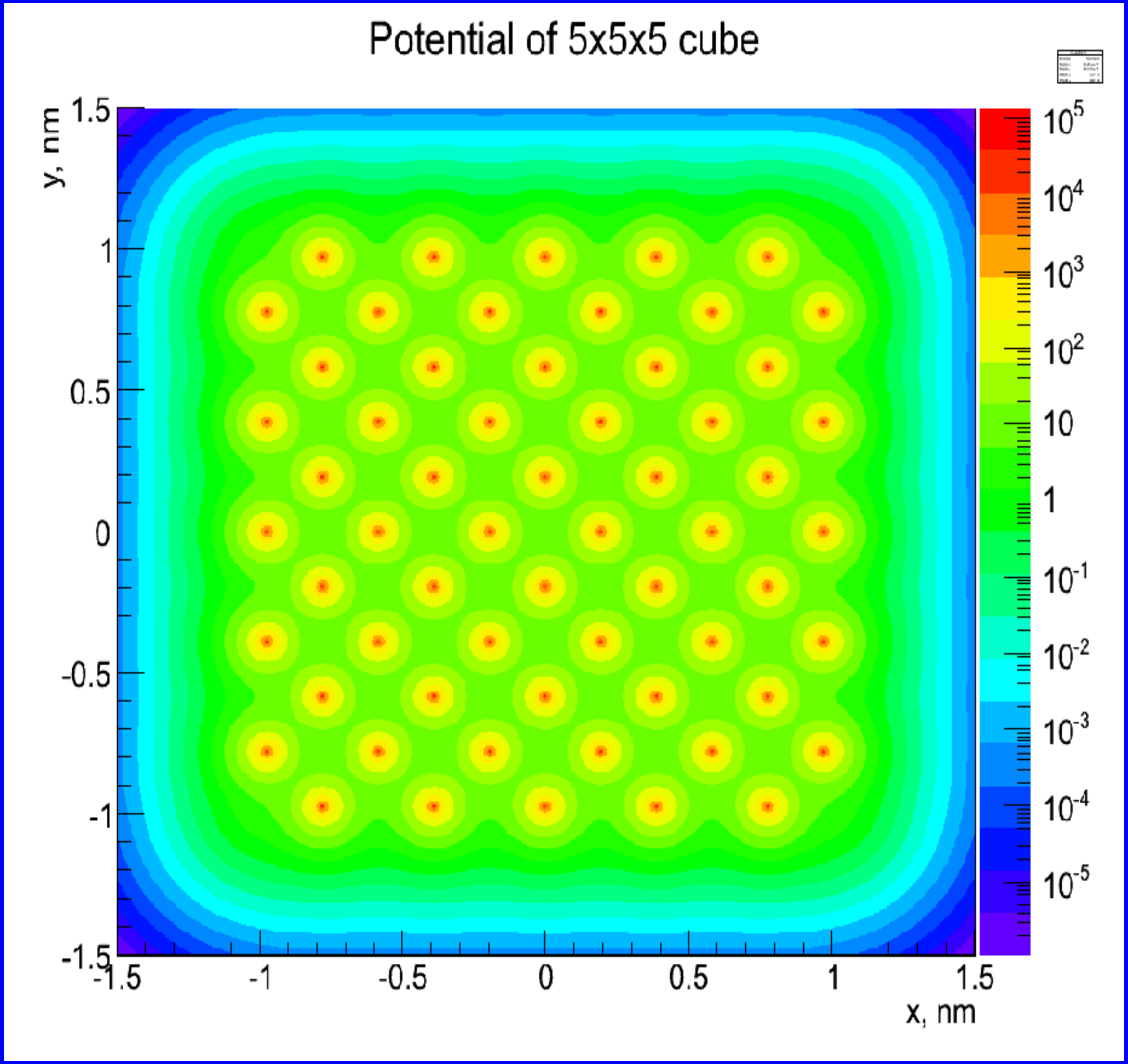
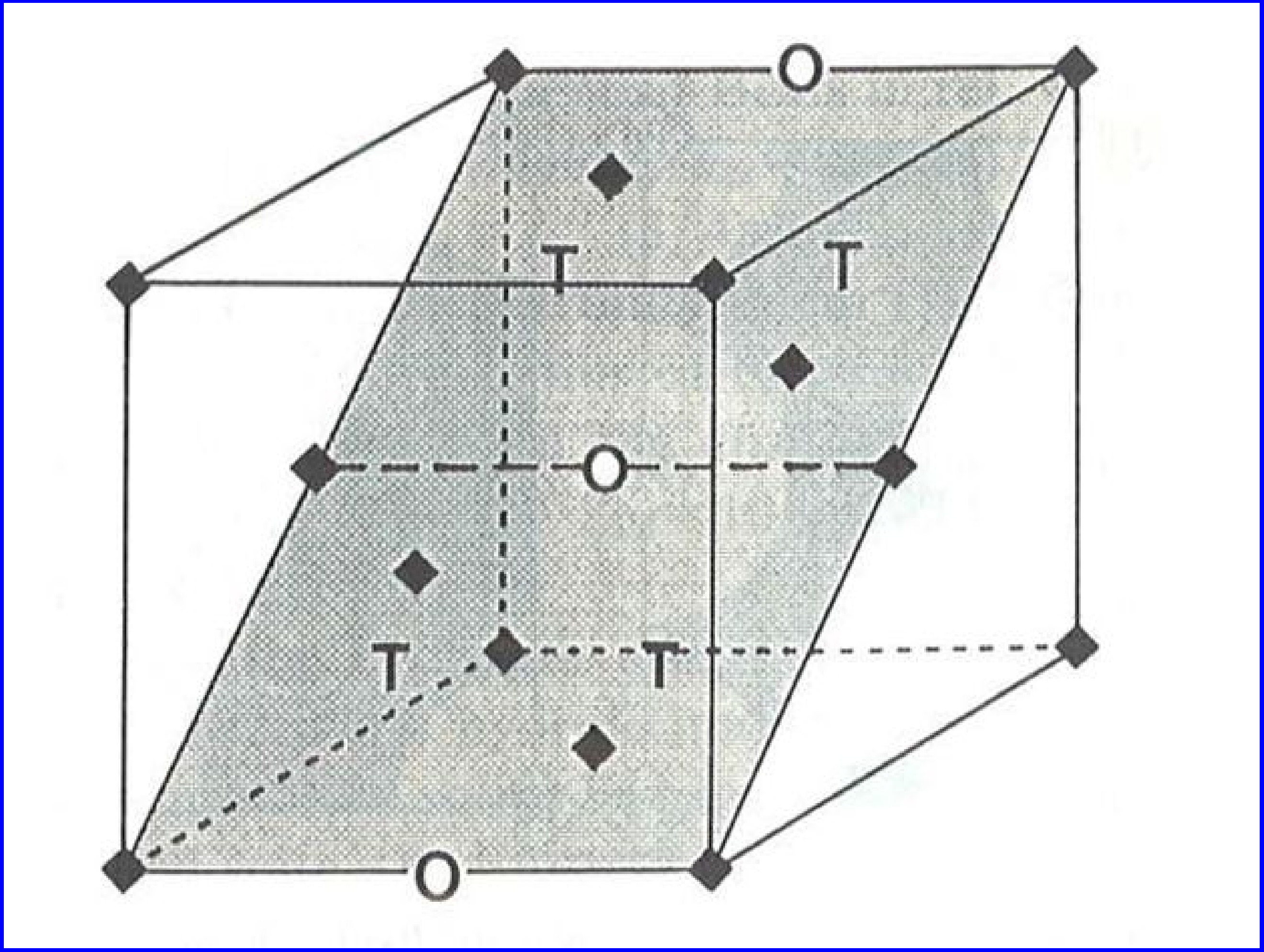
DD FUSION IN CONDUCTING CRYSTALS

The paper presents a brief background on cold fusion leading to a discussion on some aspects of atomic physics. We are explaining the selection of the only permitted orbitals of deuterium atoms in conducting crystals when saturated with deuterium. Conduction electrons in metallic crystal are grouped in potential niches of the crystal lattice, resulting in a ban for s-states of hydrogen to occupy these same niches. At the same time, the filling of these niches with deuterium atoms is allowed for the excited atomic states of level 2p and above. As has been shown in experiments on deuterium-deuterium (DD) fusion with low-energy accelerators, if an atom of deuterium target is located within a conducting crystal, this reaction is much more probable than in the case of free atoms of deuterium. When a single crystal niche gets two such atoms of deuterium, the distance between the nuclei of these atoms becomes equal to 1/10...1/20 of the nominal size of these atoms. Theoretical calculations show that this is equivalent to the additional energy 300...700 eV for the fusion reaction DD→^{4}He. We believe that this process of excitation of atomic states to the 2p level and above explains the first stage of the so-called cold fusion.*

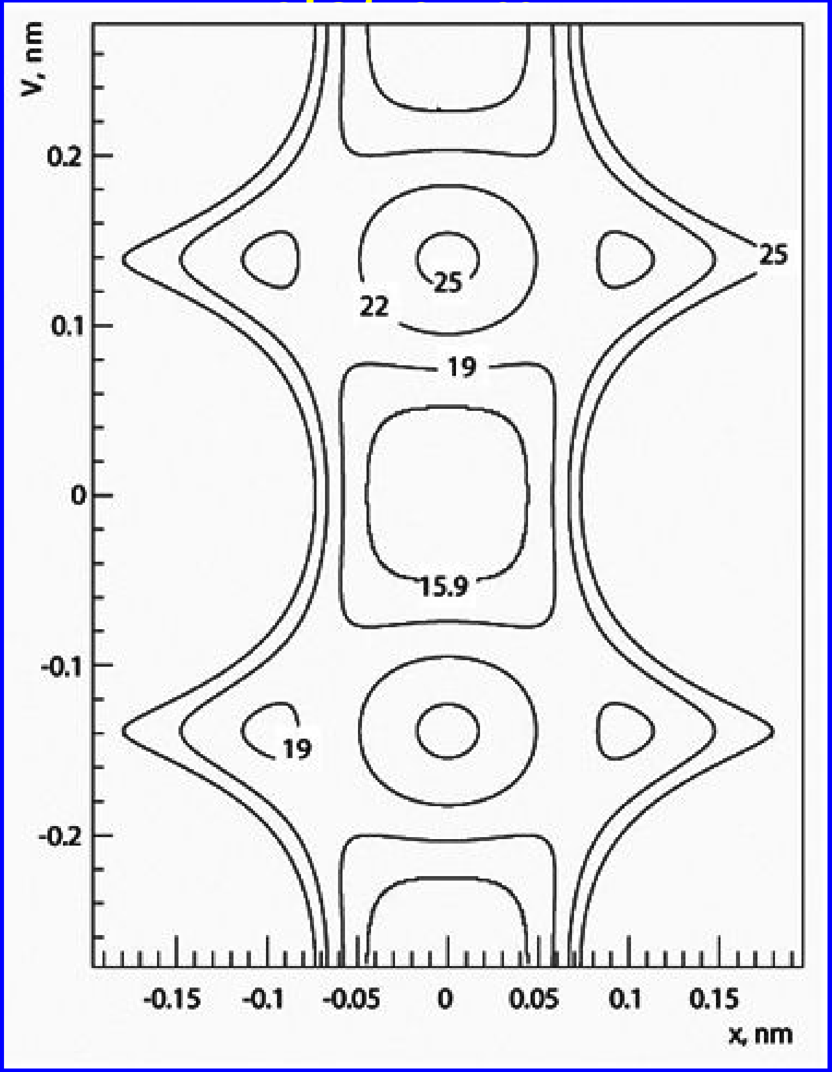
Atomic potentials of the cluster of 5×5×5 cells in the platinum crystal



Diagonal XV plane of fcc crystals. Signs O marks octahedral vacancies; signs T, tetrahedral ones.



Potential contours in the diagonal XV plane for



Potential in the vicinity of the center of octahedral niche of platinum crystal cell along the *V* direction

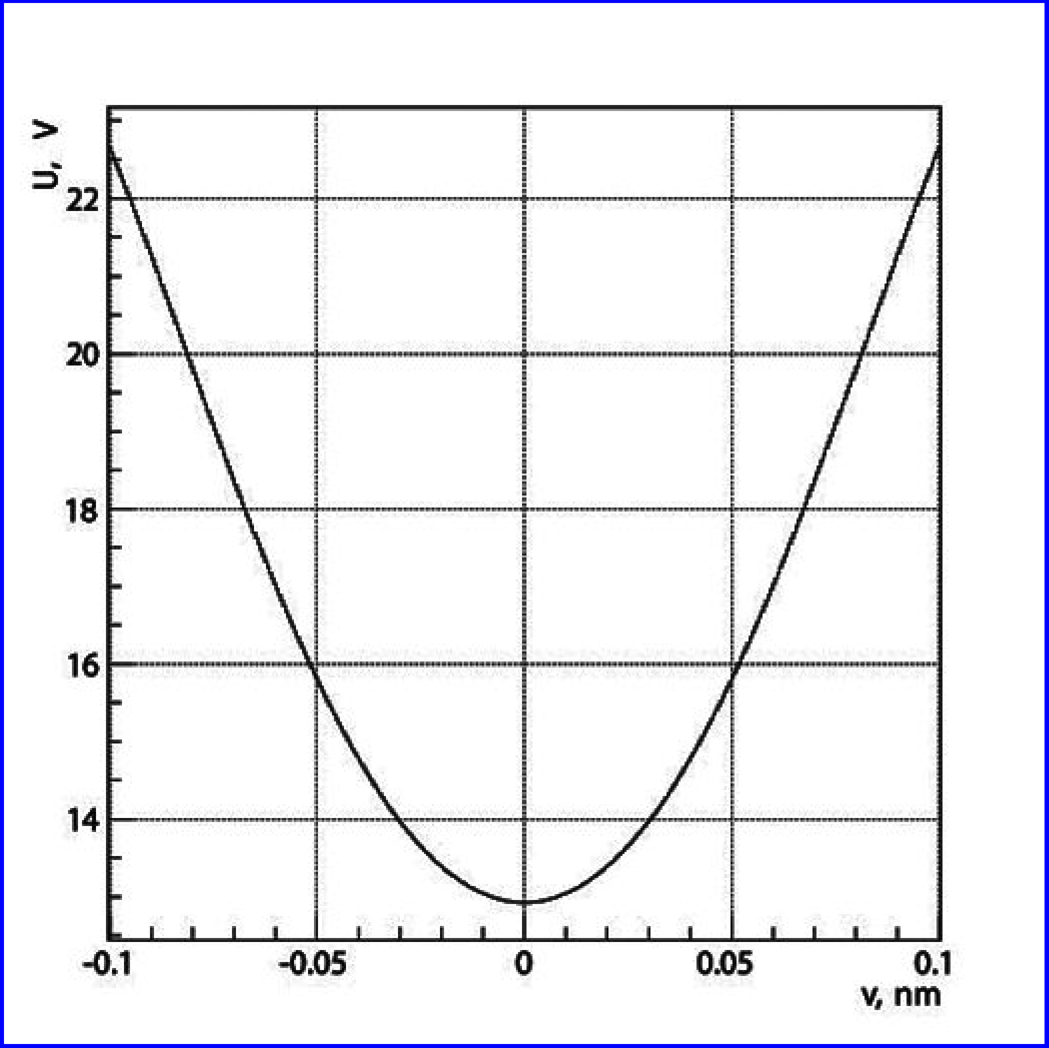
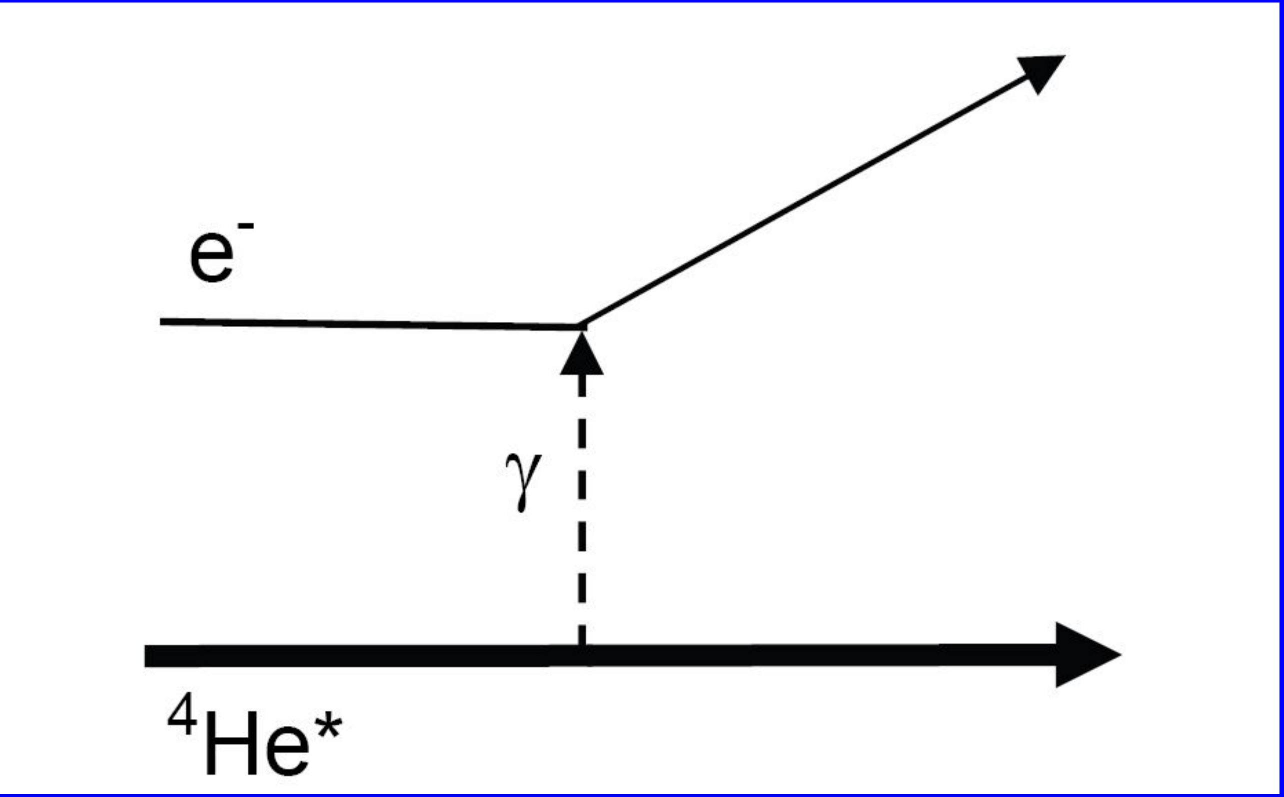
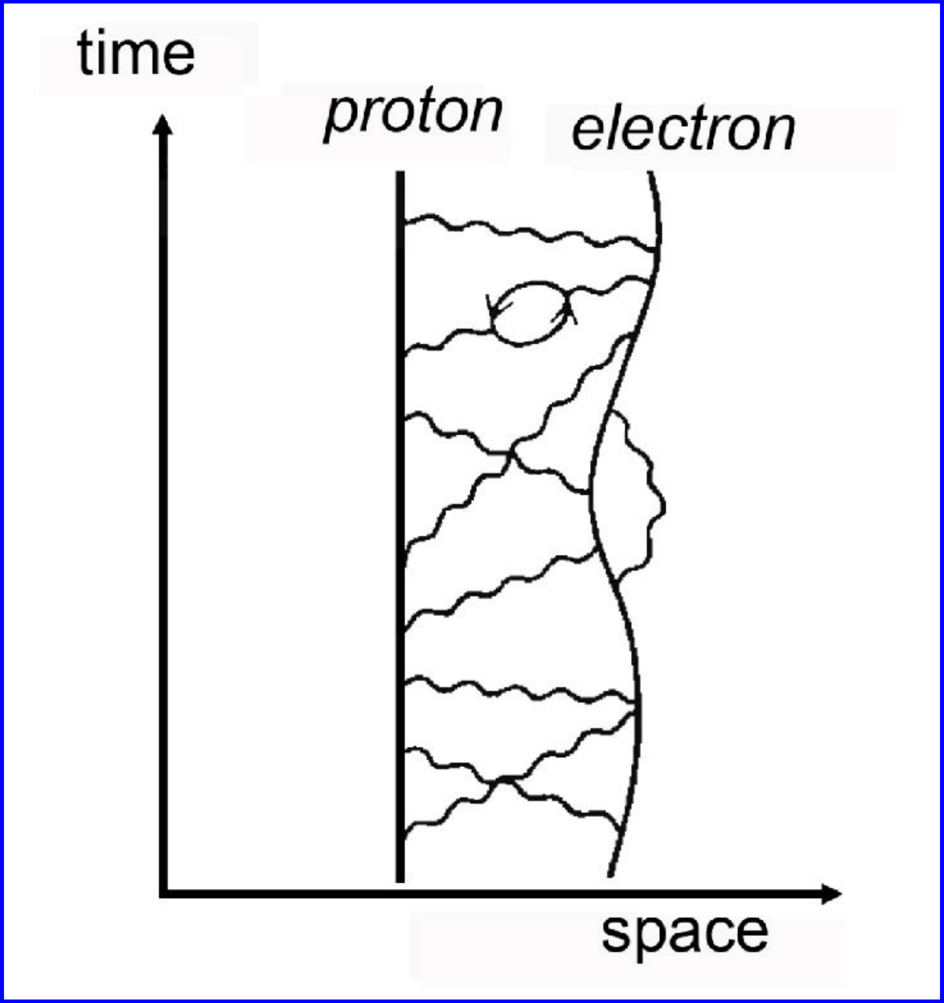


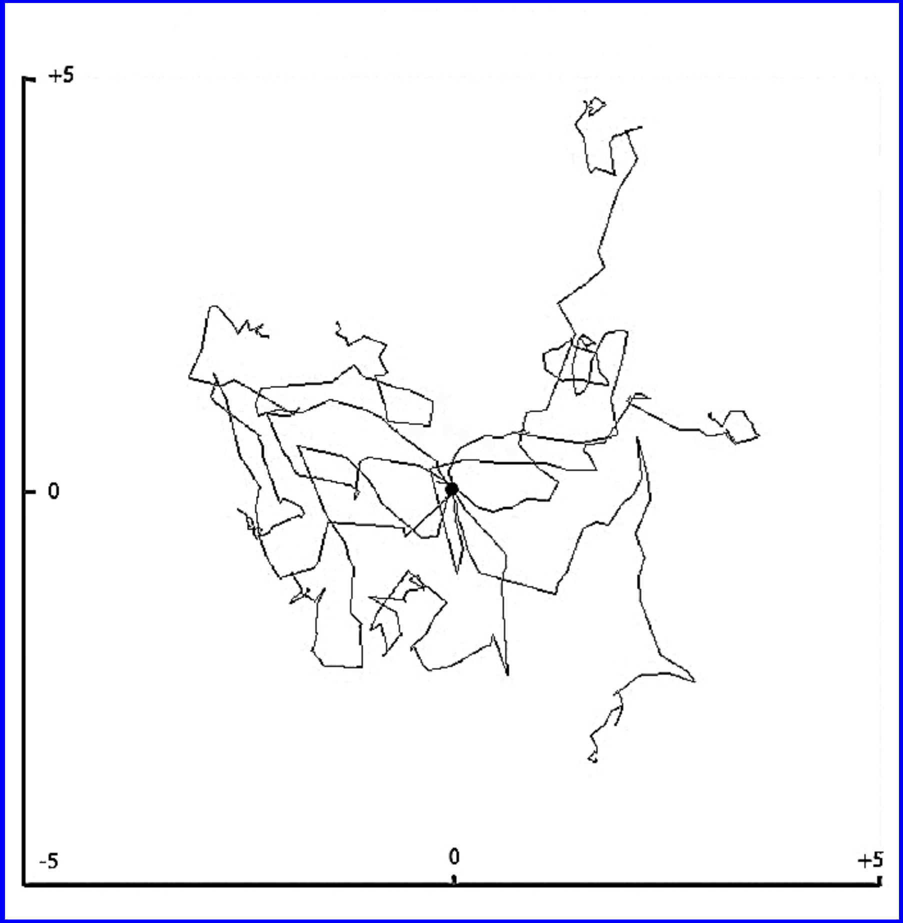
Diagram of the process, providing “thermalization” of DD fusion with the formation of 4He* in conducting crystals. In order for this process to work, the existence of a metastable state of 4He* is necessary.



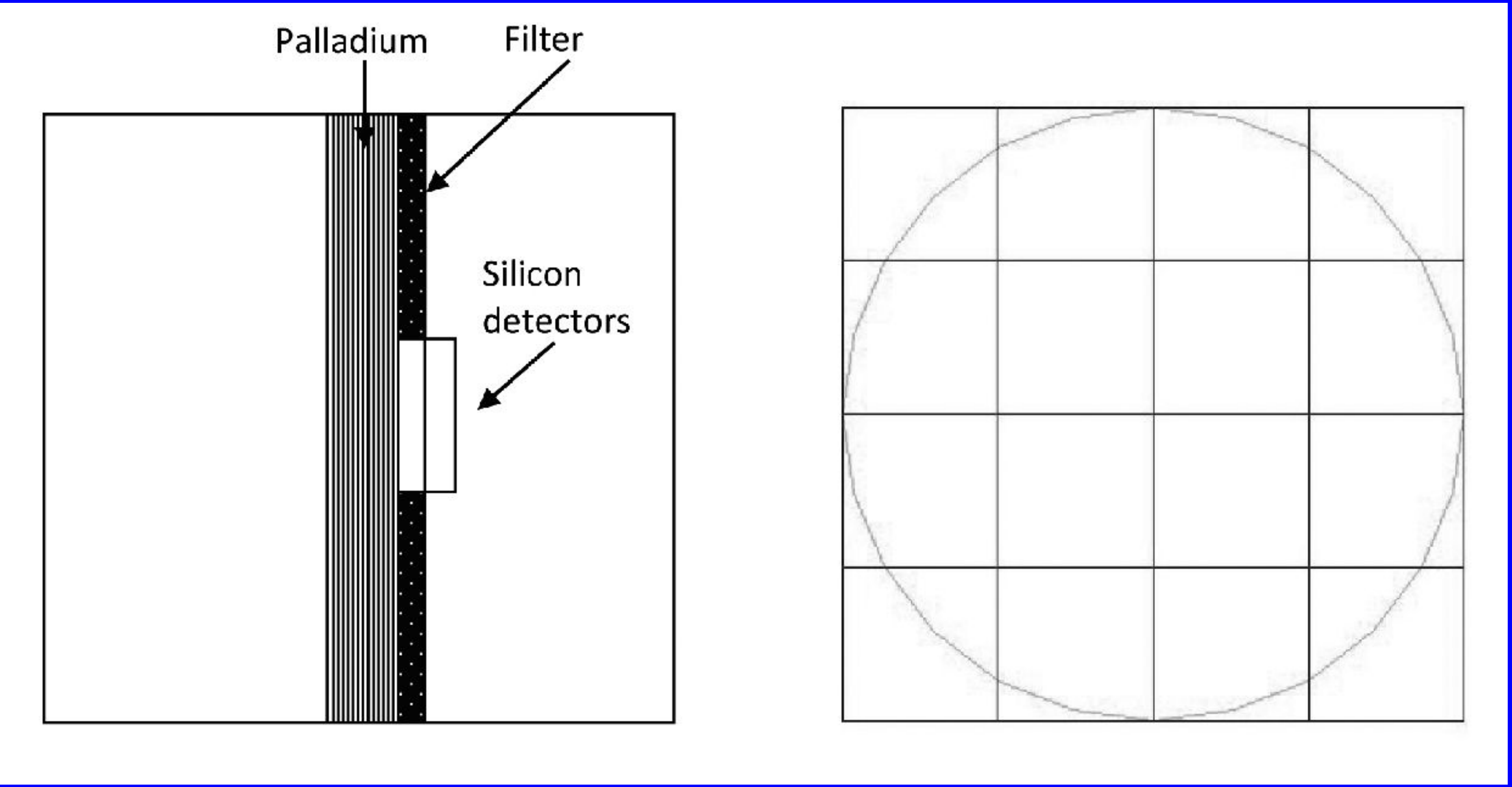
Virtual photons in the hydrogen atom (Richard Feynman)



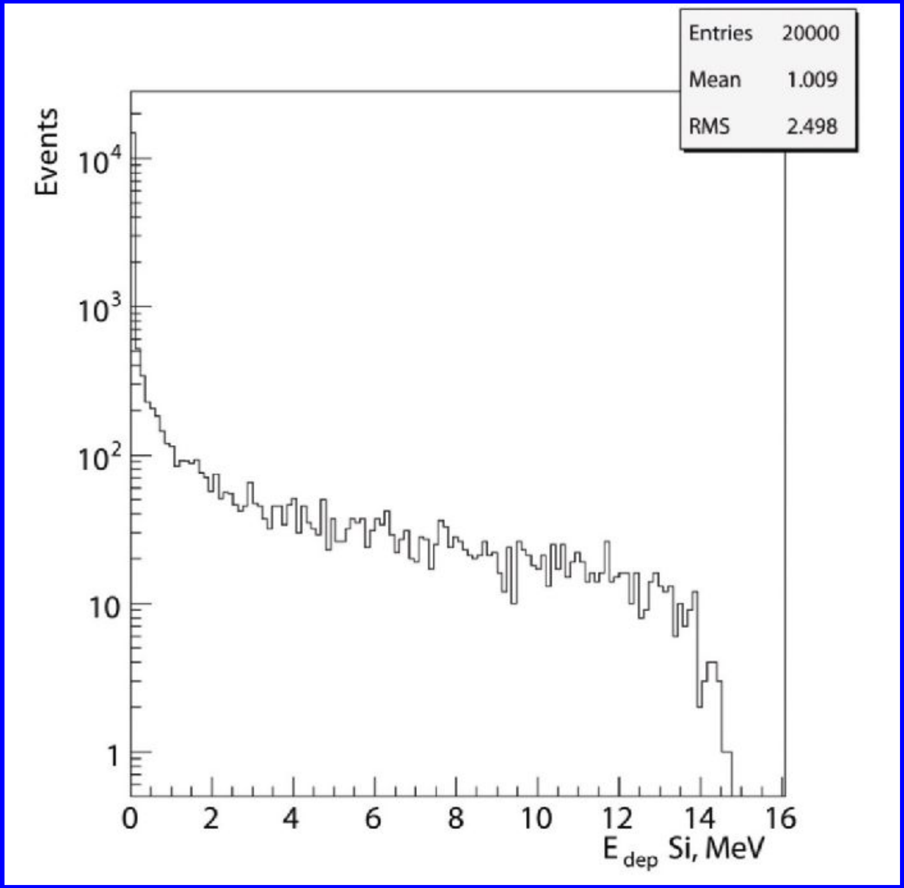
The trajectories of electrons (Monte Carlo) generated in the process of DD cold fusion in palladium. Dimensions are in micrometers.



One-side scheme of the experiment. Several silicon detectors are placed on the same side of the palladium foil and included in coincidence. Left — side view, right — the relative positions of the aperture and detectors.



Energy emitted by *60 KeV* electron in detectors placed on one side of the palladium foil. The spectrum extends up to *14 MeV*, because some of the electrons are scattered in palladium at angles up to 180 degrees.



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Conclusion (1)

1. Existence of the phenomenon of cold fusion now is conclusively proven by the experiments, including experiments on low-energy accelerators.

2. The absence of nuclear products observed in cold fusion experiments can be explained by slowing down the decay speed of a compound nucleus 4He* *via* nuclear channels with decreasing energy of its excitation. Energy release is due to virtual photons.

3. Prejudice of many nuclear physicists toward the cold fusion phenomenon is associated with this unusual nuclear process. In the cold fusion process, the resulting intermediate compound nucleus 4He* is in a metastable state.

Conclusion (2)

4. The accumulated empirical rules of nuclear physics are considered by the nuclear physics community as indisputable, while the range of application of these rules is limited.

5. Cold fusion provides many more practical opportunities than the expected traditional thermonuclear fusion. Some of the applications of cold fusion (ships, aircraft, and space travel) are simply unavailable for devices of cyclopean scale—tokomaks and other hypothetical facilities using thermonuclear fusion.

LPHE, November 15, 2012

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RASA, 8-10 November 2013, Clearwater Beach, FL

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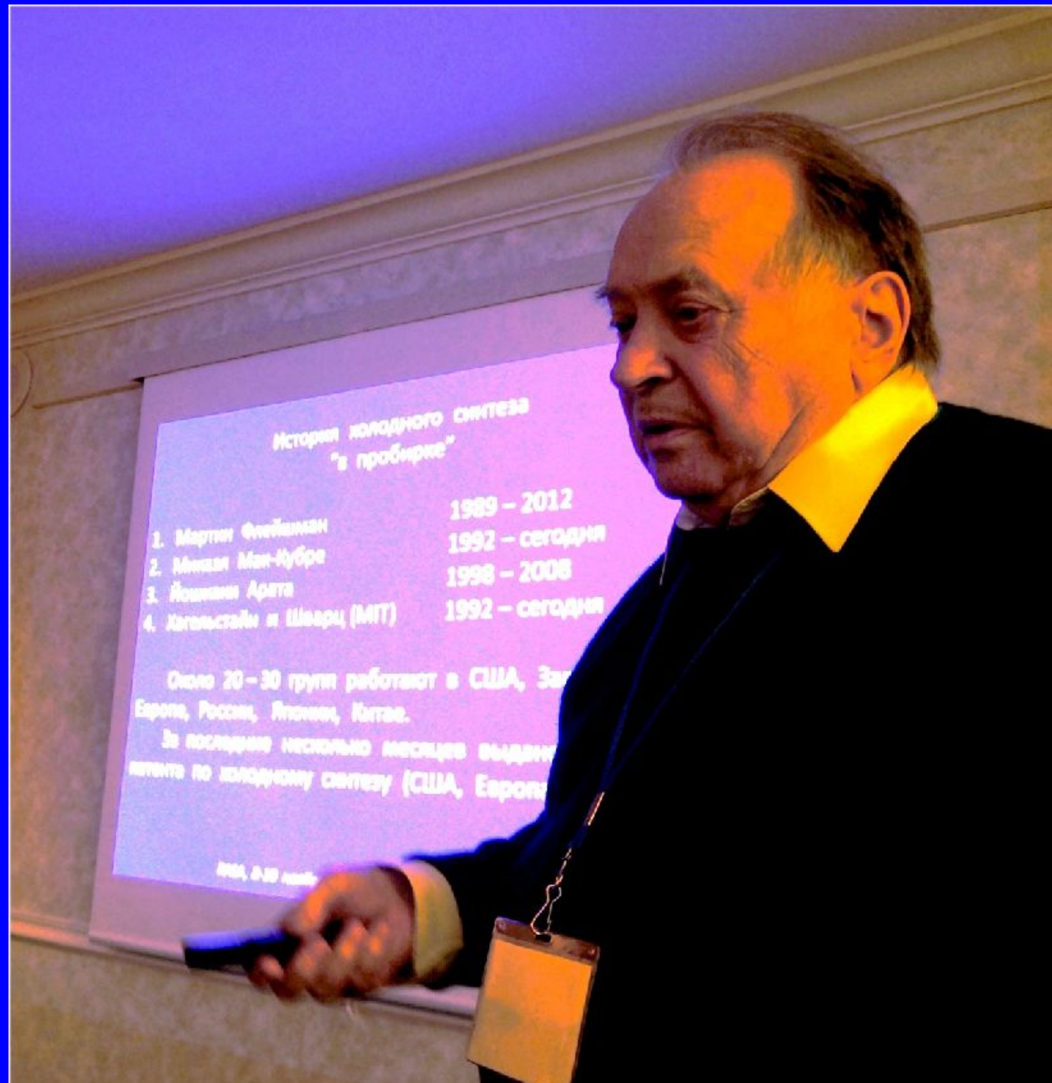

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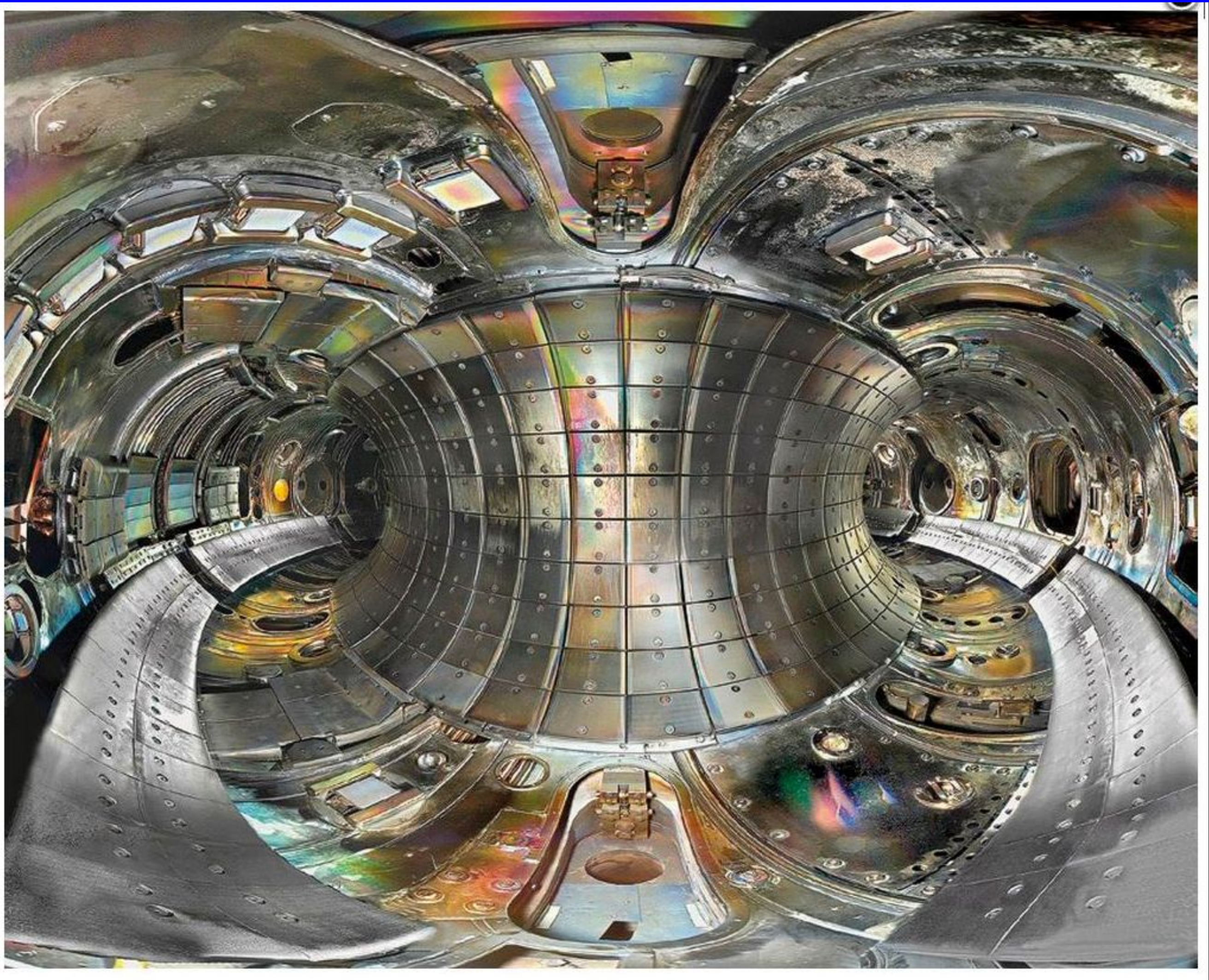
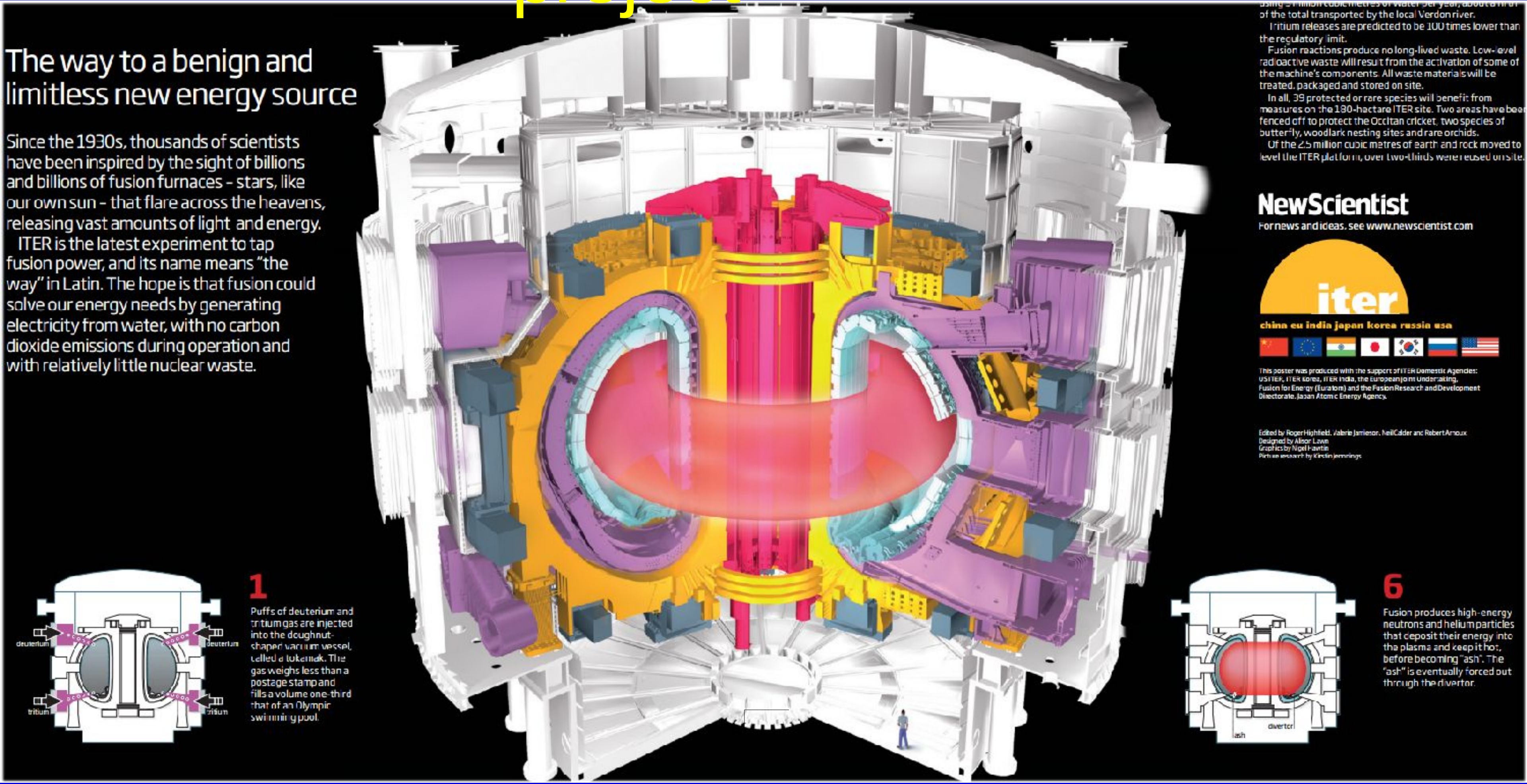


ITER project



ITER, May 2014

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Thank you for your attention!