EVALUATION OF D/D REACTION RATES IN METALLIC LATTICES AS A FUNCTION OF DEUTERON ENERGY

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Recently, experimental observations were made, showing an enhancement of d/d reaction rates, for energies of the deuteron between 3000 and 10000 eV on the one hand [1] and at very low energy of the deuteron on the other hand [2]. For both experiments, this enhancement was ascribed to the screening effect of the electrons of the metallic lattice where the reactions take place.

In [3], the contribution to the d/d reaction rate enhancement, of an attractive Yukawa type of potential, acting between nucleons, was evaluated. The combined effect of this potential and of the screening of the lattice electrons was shown not to be sufficient to explain the whole enhancement observed for both experiments [1] and [2]. A coupling between the deuterons in the target with the incident deuteron beam was thus invoked [3] to explain the enhancement observed, by fusion reactions taking place between the deuterons already trapped in the target.

Using the model developed in [3], the energy production resulting from the interaction of a 1 W beam of deuterons with a metallic target loaded with deuterium (1 mmole d), was evaluated as a function of the incident deuteron energy. 3 zones of interest were identified: a zone corresponding to hot fusion (deuteron energy round 100 000 eV), a zone corresponding to Cold Fusion (SPAWAR experiments - deuteron energy round 10 eV) and a potentially interesting intermediate zone (deuteron energy between 500 and 1000 eV) were sizeable and industrially significant amounts of energy production can be expected. It is proposed to call this last zone CMAF zone (Condensed Matter Assisted Fusion).

This approach will be detailed and practical ways to generate deuterons in the CMAF energy window will be presented.

[1] A. Huke, K. Czerski, P. Heide, G. Ruprecht N. Targosz and W.Zebrowski Enhancement of deuterons fusion reactions in metals and experimental implications. *Physical Review C*, 78:015803, 2008. [2] P.A Mossier Boss, S.Szpak, F.E Gordon, and L.P.G Forsley. Use of CR-39 in Pd/D co-deposition experiments. *Eur. Phys. J.appli. Phys*. **40**, 293-303 (2007) [3] J. Dufour. Possible existence of an attractive Yukawa type of potential and consequences on the understanding of alpha disintegration constants and d/d reactions at low energy of the deuteron. Submitted 18-02-2009 to *Physical Review C* .

THE CMAF WINDOW

Possible sizeable energy production from 500/1000 eV deuterons

Main topics covered

- I The physics and maths used in alpha disintegration constants and d/d fusion reaction rates. The Yukawa potential.
- II Determination of the coupling constant of the Yukawa potential (alpha disintegration)
- III Determination of d/d reaction rates
- IV Comparison with experimental data (Huke and SPAWAR).
- V The coupling resonnance and the CMAF window.

I - Physics and Maths
The Gamow penetration factor γ

Plays a major role

- In alpha disintegration constants
- In d/d fusion reactions rates

$$\gamma = \frac{2\sqrt{2m}}{\hbar}\int_{R_1}^{R_2}\sqrt{\left(B(r)-E\right)}\,dr \quad (m = reduced\ \ mass)$$

I - Physics and Maths Expression of the barrier

- The barrier equation is:

$$B(r) = +ke^2\left(\frac{1}{r}\right) + \frac{l(l+1)\hbar^2}{r^2} - k'Cg^2\frac{e^{-r/\rho}}{r}$$

Coulomb *Centrifugal* *Yukawa*

- With

$$k = 1 \; and \; k' = 4 \; in \; the \; d/d \; case$$
$$k = 2Z' \; and \; k' = 4A' \; in \; the \; \alpha \; case$$

. Calculation of the tunnelling probability P(Ed) using a spreadsheet

I - Physics and Maths Expression of the barrier

- The boson carrying the Yukawa interaction might be a neutral and virtual electron/ positron pair, with mass $2m_e$ (electron mass)

  (A. Meulenburg suggestion August 2008)

- Its range would be: $$\rho = \lambda\!\!\!^{-} = \frac{\hbar}{2m_e c} = 193 \;\; fm$$

- The coupling constant C can be calculated from known experimental values of the alpha disintegration constants.

II - Alpha disintegration case

- Following relations allow the determination of C (Yukawa coupling constant) by fitting calculated alpha disintegration constants λ with measured ones:

$$\lambda = \nu P$$

$$\nu = \frac{1}{2R_1}\sqrt{\frac{E_\alpha}{2m_\alpha}}$$

$$P = e^{-\gamma}$$

$$C = 3.79*10^{-6} g^2 = 7.53*10^{-3} e^2$$

III - d/d reaction rates case

- $$r(cm^{-3}s^{-1}) = \sigma(cm^{2})\varphi(cm^{-2}s^{-1})N_0(cm^{-3})$$

σ cross section $\sigma = \sigma_{geom.}P\left(E_d\right)$ probability of tunnelling

N_0 deuteron concentration in palladium

φ incident deuteron flux $(cm^{-2}s^{-1})$

- The energy produced is:

$$W = r\left(1+3+0.83+2.44\right)1.6*10^{-13}\ \left(W\ cm^{-3}\right)$$

III - d/d reaction rates case

- The d/d reaction rates were calculated (with $P(E_d)$ given by the model) for an incident deuteron flux corresponding to 1 W with energy E_d (varying from 2 to 100,000 eV) on a 1 cm2 target, containing 1 mmole of d (d/Pd = 0.7)
- Calculations were run in 2 cases : no screening and screening + action of the Yukawa potential (with strength C from the alpha case).
- The influence of the Yukawa was found negligible at a few eV (huge impact of the screening) and of the same order of magnitude as the electron screening at a few keV.

III - d/d reaction rates case

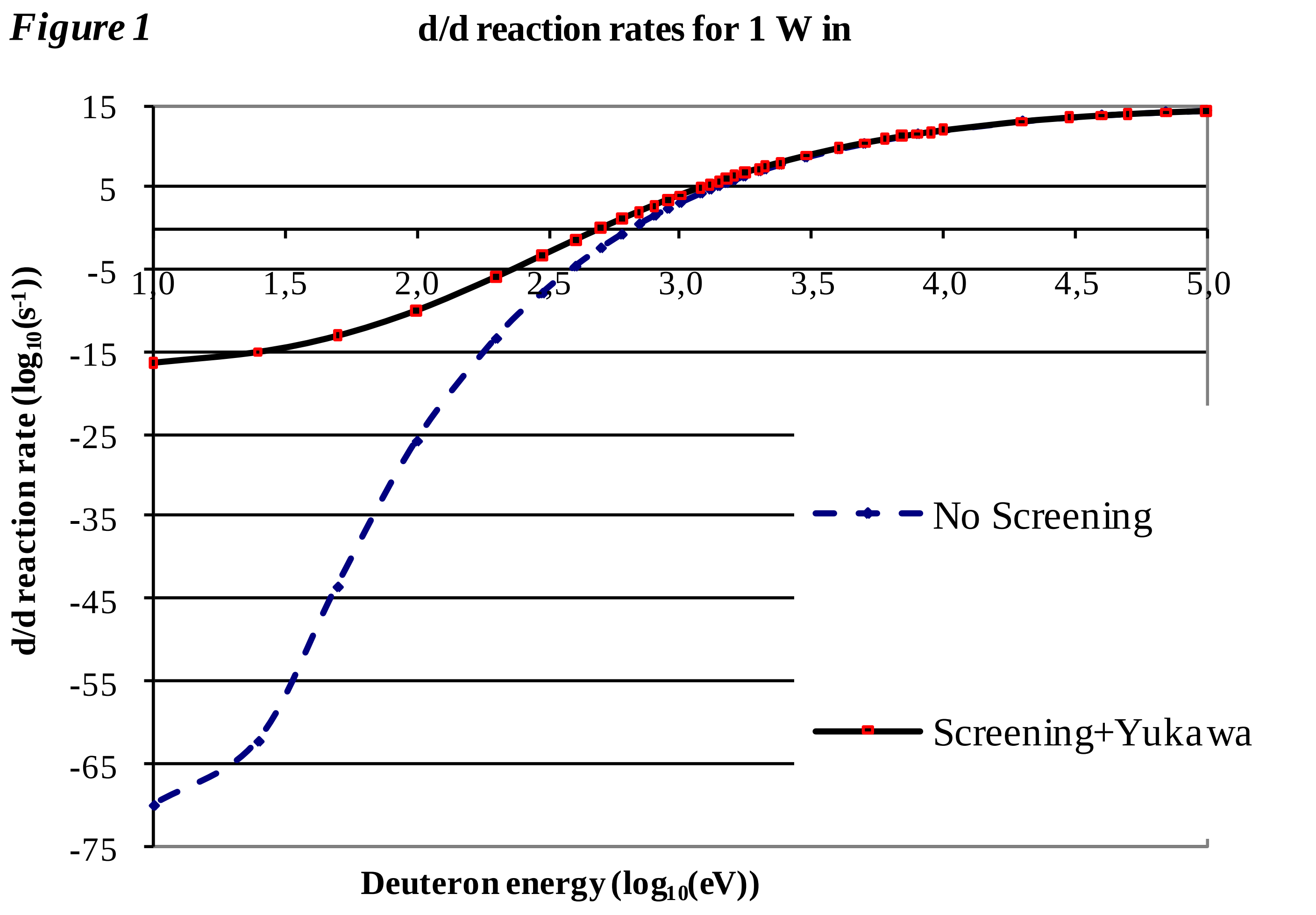
- With these hypothesis, the number of incident deuterons is: $$n = \frac{1}{100 E_d}\sqrt{\frac{\mathrm{m_d}}{2\mathrm{E_d}}}\ (\mathrm{cm^{-3}})\quad (E_d\ in\ eV)$$

  and their flux: $$\varphi = \frac{1}{\mathrm{E_d}}\ \left(cm^{-2}s^{-1}\right)$$

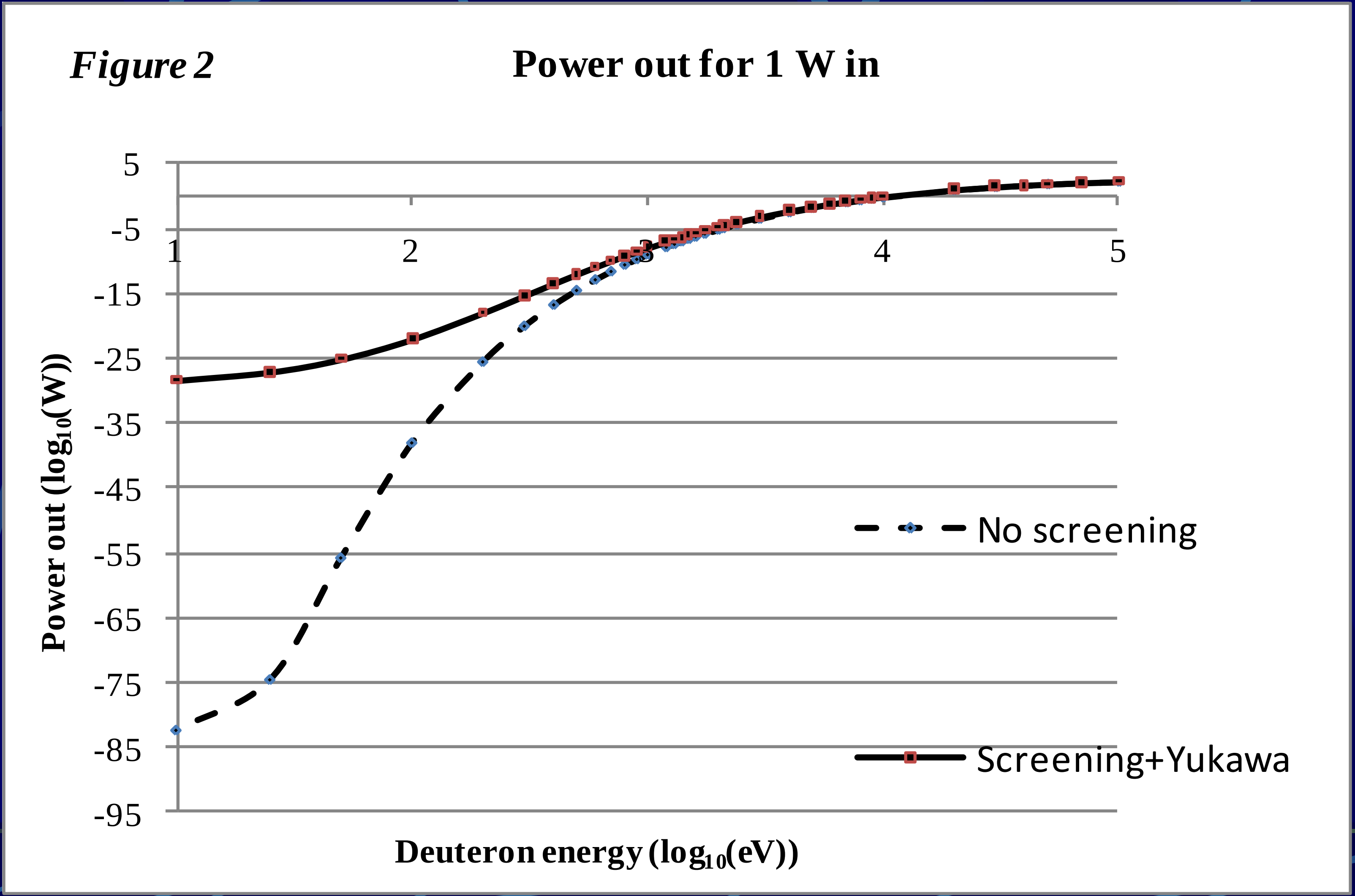
  The palladium target thickness is *126 µm,* containing 1 mmole d (*6*10²⁰* d) corresponding to $$N_0 = 4.74*10^{22}\ (cm^{-3})$$

IV - Comparison with experimental data
Calculated d/d reaction rates

Figure 1



IV Comparison with experimental data
Calculated Power out



IV - Comparison with experimental data

- Hucke results (ref.1) show experimental reaction rates r_{ex} higher than calculated ones r_{cal}, with screening and Yukawa (ref.3)

$$r_{ex} = F_c r_{cal}\,,\ \ with\ F_c = 1.5\ to\ 2$$

- SPAWAR results (ref.2) show experimental reaction rates r_{ex} very much higher than calculated ones r_{cal}, with screening and Yukawa (the latter negligible)

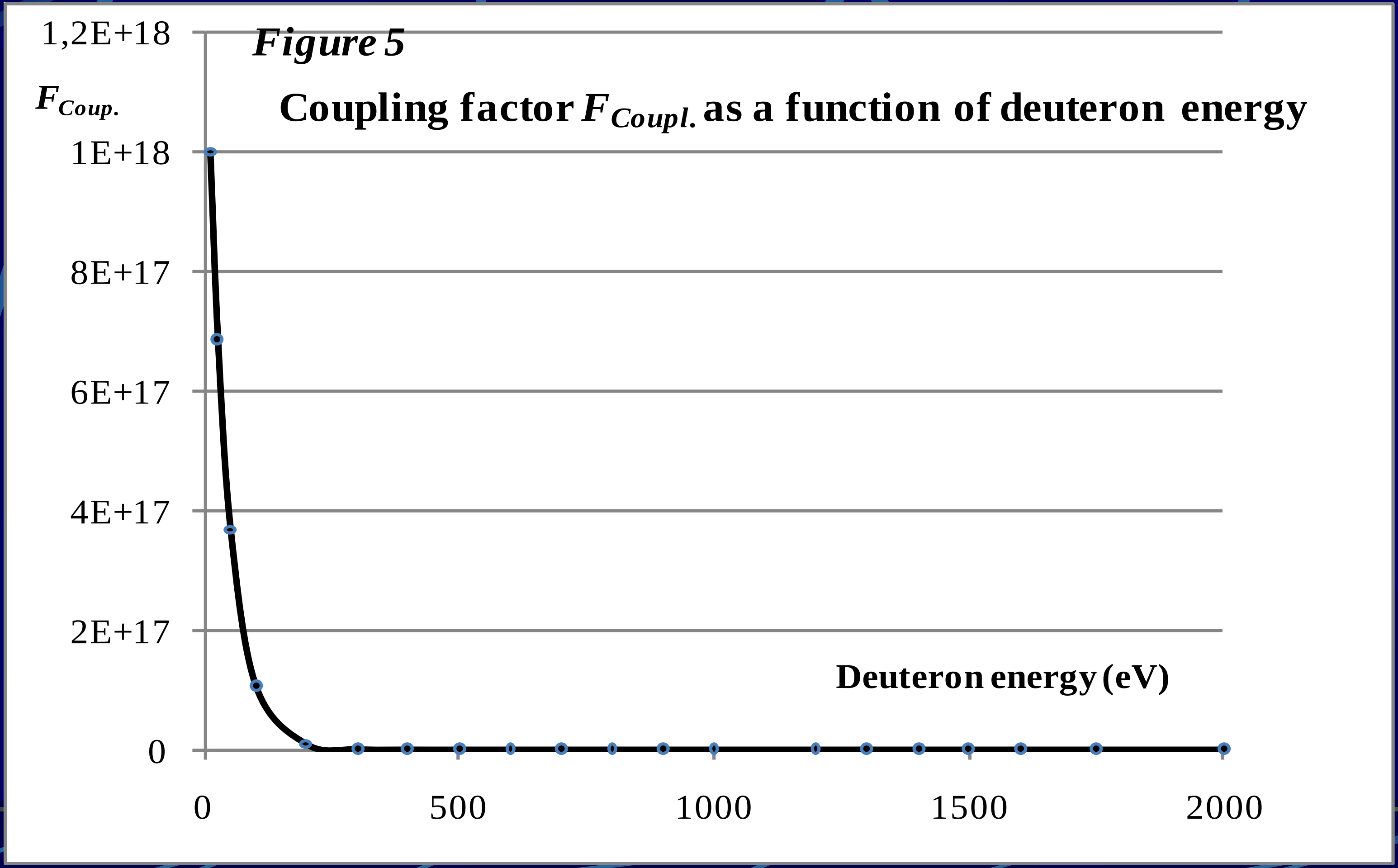
$$r_{ex} = F_c r_{cal}\,,\ \ with\ F_c \simeq 10^{18}$$

IV - Comparison experimental data versus calculated reaction rates

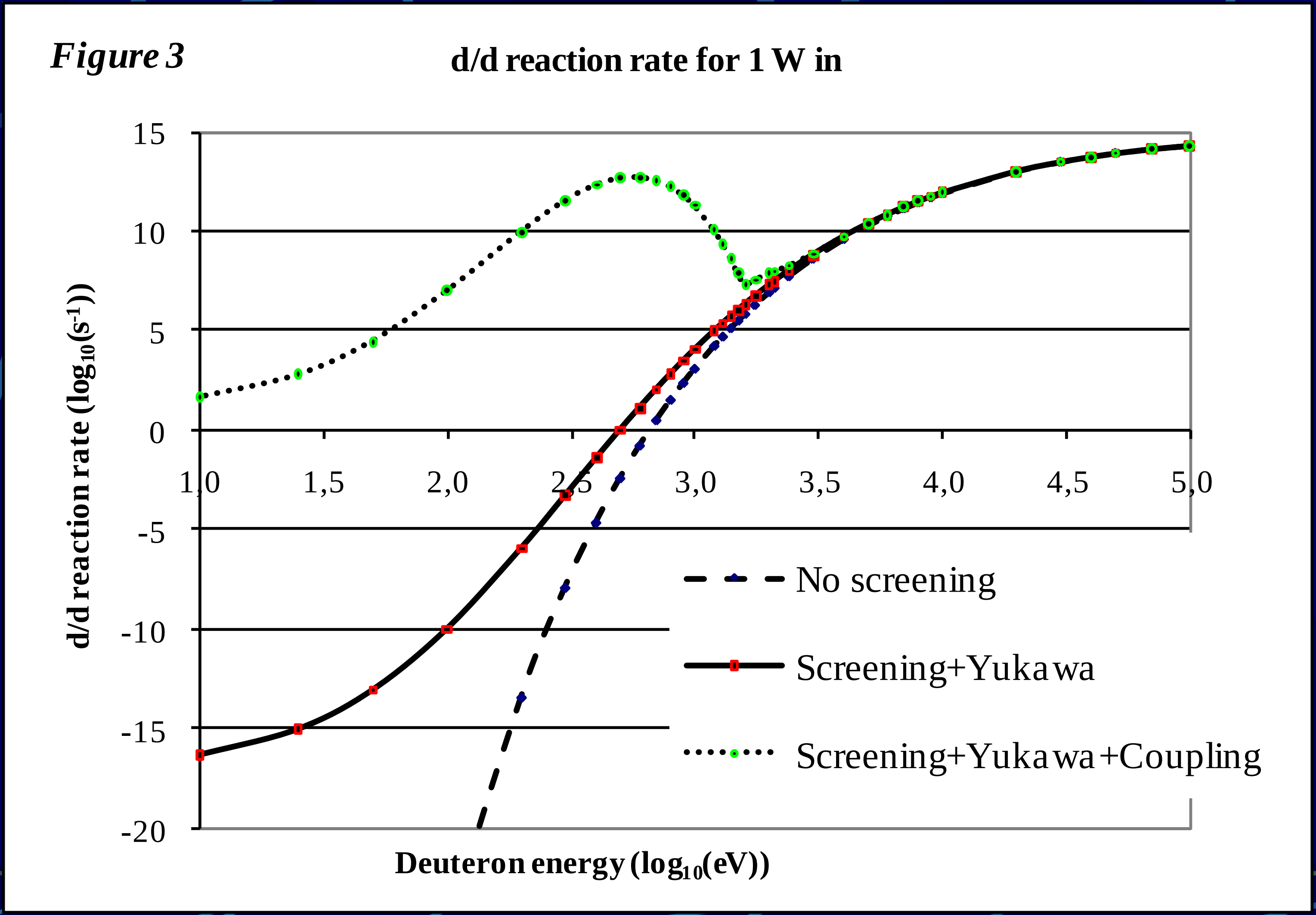
- Typical energies for Hucke experiments are 2000 to 10000 eV. For SPAWAR experiments they are round 2 eV
- The huge variation of F_c with E_d (energy of the deuteron) suggest a resonnant coupling between the impidging deuteron flux and the deuterons already present in the target (inducing fusion reactions between them).

$$F_{coupl.}(E_d) = F_{coupl.}(E_f)e^{-\Delta(F(E_f))\frac{E_d - E_f}{E_f}} \quad \text{with } E_f \textit{ fermi energy}$$

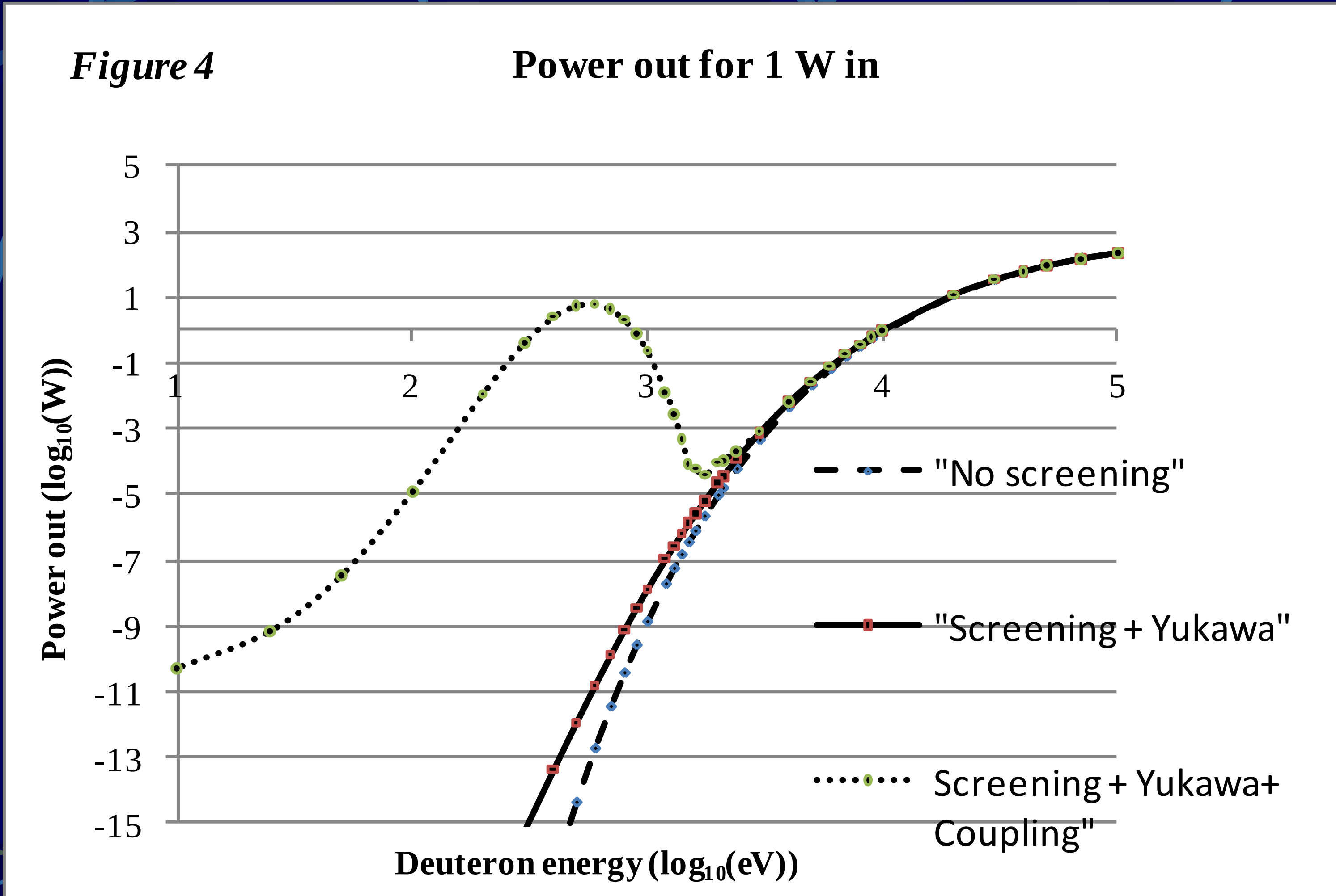
V - The coupling resonnance and the CMAF window - The resonnance curve



V - The coupling resonnance and the CMAF window - d/d reaction rates



V - The coupling resonnance and the CMAF window - Energy out for 1 W in



V - The coupling resonnance and the CMAF window - Energy out for 1 W in

- At low energy of the deuteron, the reaction rates are in line with SPAWAR results for a huge value of the coupling (#10^{18}) The Yukawa potential has a negligible role.The energy production is very small (10^{-10} *W*). At a few keV, the Yukawa potential has an influence comparable to that of the electrons screening and with a coupling factor of 1.5 to 2, the results are in line with Huke measurements.

- At high energy of the deuteron, the reaction rates are in line with hot fusion.

- At energy of the deuteron between 500 and 1000 eV, sizeable energy production levels are expected. CMAF window (Condensed Matter Assisted Fusion)

V - The coupling resonnance and the CMAF window - Production of deuterons beam in the CMAF window and target optimization

- Prototype for screening studies
- Ion guns for industrial applications
- Importance of Fc, depending upon physical and chemical characteristics of the target (optimization required).