A Conventional Explanation for a Pd-^{2}D Low Energy Nuclear Reactor

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Outline

1. Review of Previous Presentations
2. Description of Lattice Assistance
3. Example Calculation of an LENR
    - Scattering of primary child product
    - Reaction of primary child products
    - Scattering of secondary child products
    - Subsequent ^{2}d to ^{2}d chain reactions
4. Examination of neutron scattering and absorption

Background—There are Primary and Secondary Reaction in an LENR

- Consider a Low Energy Nuclear Reactor (LENR) in steady state. (^3t is ^3H. ^2d is ^2H.)
  - Two Primary reactions:
    $^2d+^2d \rightarrow ^3t+p$ and $^2d+^2d \rightarrow ^3He+n$.
  - Secondary reactions:
    $^2d+^3t \rightarrow ^4He+n$ and $^2d+^3He \rightarrow ^4He+p$.
    - No gamma radiation.
    - No neutron suppression.
    - No enhanced $^2d+^2d \rightarrow ^4He+\gamma$ reaction.
    - No unusual physics to overcome Coulomb barrier.
  - Standard physics and standard engineering can explain it.
  - As in fission, the by-products of the reactions sustain the chain reaction.
    - Can we confirm this mathematically?
    - Yes!

- The Mechanism:
  - Child products collide with the cold ^2d fuel
  - Frequently enough and energetically enough
  - Sustains the ^2d to ^2d reaction.
  - The lattice conditions must be right
    - High ^2d loading.
    - Electron stopping occurs only at very high ion energies >20 MeV.

- Start-up condition:
- If conditions for a chain reaction in the PdD_x lattice are right, then:
  - Reaction rate grows from the first initial start-up reaction to steady state.
  - This first initial reaction is caused by some external influence.

Understanding the Lattice Environment

- The PdDx lattice is critical for LENR.
  - Should not be ignored by theorists.
  - Not well studied.
- The properties of the Pd lattice are drastically changed when D (or H) is loaded into it.
  - The magnetism goes from paramagnetic to diamagnetic.
  - The electron coefficient of heat is drastically decreased.
  - It becomes a superconductor.
  - With the highest transition temperature, with no external pressure.
  - Non-linear anomalies in its electrical resistivity
  - Anomalies in the Hall effect
  - Unexplained phonon band structur
  - Ion channeling occurs
- Electron Stopping
  - Damage from energetic ions indicates that the nuclear stopping force is dominant, not the electron stopping force.
  - Electron stopping is dominant only at higher ion energies.
- Released nuclear energy is the kinetic energy of child products.
  - This kinetic energy is transferred from the child products to D fuel.
- A subsequent reaction occurs, dependent on:
  - ^{2}d loading
  - Size and shape of Pd core
  - Pressure, voltage, current, temperature
- Must have optimum value of these all parameters.

Calculations for an Example LENR Reactor

Consider an example LENR:

- Using reasonable values for the example
- One watt of power, total, from primary reactions.
  - The reaction rate is 1.71×10^{12} reactions/sec.
  - 8.55×10^{11} reactions/second for each primary reaction.
- ^{2}d density is 1-to-1 (100% loaded) in the Pd lattice.
- The palladium core is one cm^3.
- The released nuclear kinetic energy is transferred to the ^{2}d fuel via collisions.
- Kinetic energy is transferred to D fuel.
  - Causes a subsequent ^{2}d to ^{2}d reaction to occur.
  - Most child-product ions don't escape the Pd.
- Charged child-product ions don't escape the Pd.
- Child-product neutrons do escape core.
- And possibly escape reactor apparatus as well.
  - Dependent on the set-up of the experiment.

Eight different child products.

Projectile	Source of projectile	initial energy of projectile, in MeV
Proton	Primary1	3.0300
T3	Primary1	1.0100
neutron	Primary2	2.4525
He3	Primary2	0.8175
He4	Secondary1	3.5180
neutron	Secondary1	14.0720
He4	Secondary2	3.6800
Proton	Secondary2	14.7200

Overview of the Four-Part Calculation

Part 1: Determine the Number and Average Energy of Scattered ^2d from Child Products of Primary Reactions.

- A brief review of particle scattering concepts.
  - Calculate for protons with ^2d.
  - Calculate for ^3t with ^2d.
  - Calculate for ^3He with ^2d.
- A brief review of neutron scattering concepts.
  - Calculate for neutrons with ^2d.

Part 2: Determine the reaction rate of the two secondary reactions.

- A brief review of the reaction rate concepts.
  - Calculate for secondary reaction: $^3t+^2d \rightarrow ^4He+n$.
  - Calculate for secondary reaction: $^3He+^2d \rightarrow ^4He+p$.

Part 3: Determine the Number and Average Energy of Scattered ^2d from Child Products of Secondary Reactions.

- For ^4He with ^2d.
- For neutrons with ^2d.
- For ^4He with ^2d.
- For protons with ^2d.

Part 4: Determine the reaction rate of the subsequent $^2d+^2d$ reaction.

- Sum number of the energetic ^2d.
- Calculate average energy of energetic ^2d.
- Calculate rate of subsequent ^2d + ^2d reaction.
- Determine if a chain reaction might occur.

❑ All of these calculations use standard equations and standard engineering.

Particle Scattering for Charged Particles

❑ Scattering Calculations

- Similar to Rutherford scattering,
  - without approximations.
- Deflection angles in center-of-mass reference frame, Θ_{CM}:

$$Cos(\Theta_{CM}) = \left(\frac{-m_p}{m_t}\right) \times \left(Sin^2(\theta_{LAB})\right)$$

$$\pm\left[\left(\left(\left(\frac{m_p}{m_t}\right)^2\right) \times \left(Sin^4(\theta_{LAB})\right) - \left(\left(\frac{m_p}{m_t}\right)^2\right) \times \left(Sin^2(\theta_{LAB})\right) + Cos^2(\theta_{LAB})\right)\right]^{1/2}$$

- The kinetic energies use reduced mass, μ.

$$\mu = \frac{m_p m_t}{m_p + m_t}$$

where:
θ_{LAB} is deflection angle in lab reference frame
m_p is projectile mass
m_t is target mass.

- The final velocity of the projectile:

$$\left(\frac{v_{pf\_lab}}{v_{pi\_lab}}\right) = \frac{\left(m_p^2 + 2m_t m_p Cos(\Theta_{CM}) + m_t^2\right)^{1/2}}{\left(m_p + m_t\right)}$$

- The final energy of the projectile:

$$\frac{E_{pf}}{E_{pi}} = \frac{\left(m_p^2 + 2m_t m_p Cos(\Theta_{CM}) + m_t^2\right)}{\left(m_p + m_t\right)^2} \qquad \text{Eq. 1}$$

- The final energy of the target is the difference.

$$E_{tf} = E_{pi} - E_{pf}$$

where:
E_{pi} = projectile initial energy, lab
E_{pf} = projectile final energy, lab
E_{ti} = target initial energy, lab
E_{tf} = target final energy, lab

Continued--Particle Scattering for Charged Particles

- First Goal: Number of successfully scattered ^2d.
  - Successful = 0.1 MeV or more.
- Second Goal: Average Energy of successfully scattered ^2d.
  - To achieve these two goals, we find:
    - **Impact parameter**, b:

$$b = \frac{(k)(Z_p)(Z_t)(e^2)}{(2)(E_{total\_cm})} \times \sqrt{\left(\frac{1 + \mathrm{Cos}(\Theta_{CM})}{1 - \mathrm{Cos}(\Theta_{CM})}\right)}$$

    - **Scattering cross section**, σ:

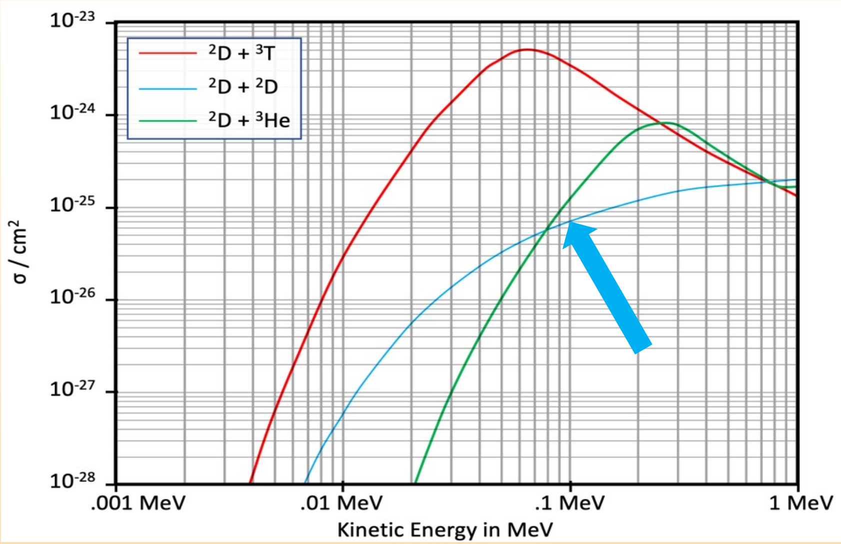
$$\sigma = \pi b^2$$

$$\sigma = \left(\frac{\pi k Z_p Z_t e^2}{\mu v_{pi}^2}\right)^2 \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM}}{2}\right)}\right)\right]$$

    - The **probability function** P for only one angle:

$$P(\Theta_{CM}) = \left(\frac{\pi \rho L N_{Avog}}{A}\right)\left(\frac{k Z_p Z_t e^2}{\mu v_{pi}^2}\right)^2 \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM}}{2}\right)}\right) - \left(\frac{1}{Tan^2\left(\frac{\Theta_{CM}+1^\circ}{2}\right)}\right)\right]$$

where:
L is the length between scatters.
ρ is the target density in kg/m^3.



Threshold value for ^2D+^2D reaction cross section is around 0.1 MeV. (blue arrow.)

- The probability function, combined with the energy function (Eq. 1), allows us to calculate number and average energy of successfully scattered ^2d:

$$E_{average\_pf} = \frac{\int P(\Theta_{CM}) E(\Theta_{CM}) d\Theta_{CM}}{\int P(\Theta_{CM}) d\Theta_{CM}}$$

Continued--Particle Scattering for Charged Particles

Combining with Eq. 1, the integral for the Average Energy is this:

$$\frac{E_{expect\_pf}}{E_{ip}} = \frac{\int \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM}}{2}\right)} - \frac{1}{Tan^2\left(\frac{\Theta_{CM}+1^\circ}{2}\right)}\right)\left(\frac{\left(m_p^2+2m_t m_p Cos(\Theta_{CM})+m_t^2\right)}{\left(m_p+m_t\right)^2}\right)\right]d\Theta_{CM}}{\int \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM}}{2}\right)} - \frac{1}{Tan^2\left(\frac{\Theta_{CM}+1^\circ}{2}\right)}\right)\right]d\Theta_{CM}}$$

The integration limits are: $\Theta_{\mathrm{CM\_max}} = 180°$

$$\Theta_{CM\_min} = 2 \times ArcCot\left[\left(\frac{\mu b_{max} v_{pi}^2}{ke^2 Z_p Z_t}\right)\right]$$

$$\Theta_{CM\_success} = ArcCos\left[\frac{\frac{E_{pf\_success}}{E_{pi}}\left(m_p+m_t\right)^2 - m_p^2 - m_t^2}{\left(2m_p m_t\right)}\right]$$

The average energy is determined using numerical integration:

$$\frac{E_{average\_pf}}{E_{ip}} = \frac{\sum_{\mathrm{i}=\Theta_{CM\_success}}^{\Theta_{CM\_max}} \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM\ i}}{2}\right)} - \frac{1}{Tan^2\left(\frac{\Theta_{CM\ i}+\Delta\Theta_{CM}{}^\circ}{2}\right)}\right)\left(\frac{\left(m_p^2+2m_t m_o Cos(\Theta_{CM})+m_t^2\right)}{\left(m_t+m_p\right)^2}\right)\Delta\Theta_{CM}\right]}{\sum_{\mathrm{i}=\Theta_{CM\_min}}^{\Theta_{CM\_max}} \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM\ i}}{2}\right)} - \frac{1}{Tan^2\left(\frac{\Theta_{CM\ i}+\Delta\Theta_{CM}}{2}\right)}\right)\Delta\Theta_{CM}\right]}$$

Continued--Particle Scattering for Charged Particles

- To find the number of "successful" scattering events, this equation is used, with appropriate integration limits.

$$fraction_{successful} = \frac{\sum_{\mathrm{i}=\Theta_{CM\_success}}^{\Theta_{CM\_max}} \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM\_i}}{2}\right)} - \frac{1}{Tan^2\left(\frac{\Theta_{CM\_i+1}}{2}\right)} \right) \Delta\Theta_{CM} \right]}{\sum_{\mathrm{i}=\Theta_{CM\_min}}^{\Theta_{CM\_max}} \left[\left(\frac{1}{Tan^2\left(\frac{\Theta_{CM\_i}}{2}\right)} - \frac{1}{Tan^2\left(\frac{\Theta_{CM\_i+1}}{2}\right)} \right) \Delta\Theta_{CM} \right]}$$

- With these equations, the number and the average energy of the successfully scattered ^{2}D can be calculated.

Here's a small sample of the very large table used for the numeric integrations. This one is just for protons. A similar table must be made for every projectile type.

A	B	C	D	E	F
Θ_{CM} in degrees	**Θ_{CM} in radians**	**$\Delta\Theta_{CM}$ in radians**	**Probability $P(\Theta_{CM})$**	**$P(\Theta) \times \Delta\Theta$**	**$P(\Theta) \times \Delta\Theta \times E_{pf}(\Theta)/E_{pi}(\Theta)$**
0.0001	1.745E-06	1.745E-06			
0.0002	3.491E-06	1.745E-06	1.824E+11	3.183E+05	3.183E+05
0.0003	5.236E-06	1.745E-06	6.383E+10	1.114E+05	1.114E+05
0.0004	6.981E-06	1.745E-06	2.955E+10	5.157E+04	5.157E+04
0.0005	8.727E-06	1.745E-06	1.605E+10	2.801E+04	2.801E+04
0.0006	1.047E-05	1.745E-06	9.677E+09	1.689E+04	1.689E+04
0.0007	1.222E-05	1.745E-06	6.281E+09	1.096E+04	1.096E+04
0.0008	1.396E-05	1.745E-06	4.306E+09	7.516E+03	7.516E+03
0.0009	1.571E-05	1.745E-06	3.080E+09	5.376E+03	5.376E+03
0.0010	1.745E-05	1.745E-06	2.279E+09	3.978E+03	3.978E+03
0.0011	1.920E-05	1.745E-06	1.733E+09	3.025E+03	3.025E+03
...	...	...	...	...	...
179	3.124139	1.745E-02	7.616E-05	1.329E-06	1.478E-07

- These numeric integrations must be done for every energy that the projectile passes through, as it thermalizes.

Calculate the scattering rate of energetic protons with ^{2}d

The results, for every energy from 3.03 MeV to 0.1 MeV, in steps of 0.1 MeV.

A	B	C	D	E	F	G	H	I	J	K	L	M	N
E_{pi} in MeV	For the energy in each row, Θ_{CM_min} in degrees, rounded.	The numerical integration of $P(\Theta)$, summed from Θ_{CM_min} to Θ_{CM_max}.	The numerical integration of $P(\Theta)*(E_{pf}/E_{pi})$, summed from Θ_{CM_min} to Θ_{CM_max}.	Expectation energy $E_{pf}(\Theta)$ in MeV, from Θ_{min} to Θ_{max}.	Lab reference frame angle, where successful scattering starts. Rounded.	The numerical integration of $P(\Theta)$, summed from $\Theta_{CM\_success}$ to Θ_{CM_max}.	Fraction of successful scatters after one collsion.	Fractional energy loss per collision	Average number of times, N, the projectile collides before falling to the next lower energy level.	Expectation value of E_{pf} for the successful scatterers only, in MeV.	Number of successful scatters.	Expectation energy E_{tf} for the ^{2}D targets, for successful scatters, in MeV.	Expectation energy E_{tf} for only the successful scatters times number of successful scatters
3.03	0.0003	1.459E+11	1.459E+11	3.0299999996	15.0	2.699436	1.814E-10	1.390E-10	7.16E+07	2.6994	1.11E+10	0.3306	3.67E+09
3.0	0.0003	1.459E+11	1.459E+11	2.9999999996	15.0	2.672709	1.814E-10	1.390E-10	2.44E+08	2.6727	3.78E+10	0.3273	1.24E+10
2.9	0.0003	1.459E+11	1.459E+11	2.8999999996	16.0	2.540843	1.517E-10	1.390E-10	2.52E+08	2.5408	3.27E+10	0.3592	1.18E+10
2.8	0.0004	8.207E+10	8.207E+10	2.7999999993	16.0	2.453228	2.697E-10	2.424E-10	1.50E+08	2.4532	3.46E+10	0.3468	1.20E+10
2.7	0.0004	8.207E+10	8.207E+10	2.6999999993	16.0	2.365613	2.697E-10	2.424E-10	1.56E+08	2.3656	3.59E+10	0.3344	1.20E+10
2.6	0.0004	8.207E+10	8.207E+10	2.5999999994	17.0	2.258490	2.479E-10	2.424E-10	1.62E+08	2.2585	3.43E+10	0.3415	1.17E+10
2.5	0.0004	8.207E+10	8.207E+10	2.4999999994	17.0	2.171625	2.479E-10	2.424E-10	1.68E+08	2.1716	3.57E+10	0.3284	1.17E+10
2.4	0.0004	8.207E+10	8.207E+10	2.3999999994	17.0	2.084760	2.479E-10	2.424E-10	1.76E+08	2.0848	3.72E+10	0.3152	1.17E+10
2.3	0.0004	8.207E+10	8.207E+10	2.2999999994	18.0	1.962881	2.114E-10	2.424E-10	1.83E+08	1.9629	3.31E+10	0.3371	1.12E+10
2.2	0.0005	5.252E+10	5.252E+10	2.1999999992	18.0	1.877539	3.303E-10	3.727E-10	1.25E+08	1.8775	3.53E+10	0.3225	1.14E+10
2.1	0.0005	5.252E+10	5.252E+10	2.0999999992	18.0	1.792196	3.303E-10	3.727E-10	1.31E+08	1.7922	3.70E+10	0.3078	1.14E+10
2	0.0005	5.252E+10	5.252E+10	1.9999999993	19.0	1.691439	3.063E-10	3.727E-10	1.38E+08	1.6914	3.60E+10	0.3086	1.11E+10
1.9	0.0005	5.252E+10	5.252E+10	1.8999999993	19.0	1.606868	3.063E-10	3.727E-10	1.45E+08	1.6069	3.80E+10	0.2931	1.11E+10
1.8	0.0006	3.648E+10	3.648E+10	1.7999999990	20.0	1.494265	3.818E-10	5.292E-10	1.08E+08	1.4943	3.53E+10	0.3057	1.08E+10
1.7	0.0006	3.648E+10	3.648E+10	1.6999999991	20.0	1.411250	3.818E-10	5.292E-10	1.15E+08	1.4112	3.74E+10	0.2888	1.08E+10
1.6	0.0006	3.648E+10	3.648E+10	1.5999999992	21.0	1.315668	3.565E-10	5.292E-10	1.22E+08	1.3157	3.72E+10	0.2843	1.06E+10
1.5	0.0007	2.680E+10	2.680E+10	1.4999999989	22.0	1.209712	4.253E-10	7.115E-10	9.70E+07	1.2097	3.53E+10	0.2903	1.02E+10
1.4	0.0007	2.680E+10	2.680E+10	1.3999999990	23.0	1.117929	3.992E-10	7.115E-10	1.04E+08	1.1179	3.56E+10	0.2821	1.00E+10
1.3	0.0008	2.052E+10	2.052E+10	1.2999999988	23.0	1.038077	5.214E-10	9.192E-10	8.71E+07	1.0381	3.88E+10	0.2619	1.02E+10
1.2	0.0008	2.052E+10	2.052E+10	1.1999999989	24.0	0.939054	4.617E-10	9.192E-10	9.47E+07	0.9391	3.74E+10	0.2609	9.75E+09
1.1	0.0009	1.621E+10	1.621E+10	1.0999999987	26.0	0.834320	4.919E-10	1.152E-09	8.27E+07	0.8343	3.48E+10	0.2657	9.25E+09
1	0.0010	1.313E+10	1.313E+10	0.9999999986	27.0	0.750435	5.749E-10	1.409E-09	7.48E+07	0.7504	3.67E+10	0.2496	9.17E+09
0.9	0.0011	1.085E+10	1.085E+10	0.8999999985	28.0	0.660922	6.253E-10	1.691E-09	6.97E+07	0.6609	3.72E+10	0.2391	8.90E+09
0.8	0.0013	7.770E+09	7.770E+09	0.7999999981	30.0	0.574639	7.884E-10	2.326E-09	5.74E+07	0.5746	3.87E+10	0.2254	8.72E+09
0.7	0.0014	6.700E+09	6.700E+09	0.6999999981	32.0	0.486005	7.895E-10	2.680E-09	5.75E+07	0.4860	3.88E+10	0.2140	8.31E+09
0.6	0.0017	4.544E+09	4.544E+09	0.5999999977	35.0	0.392798	9.252E-10	3.880E-09	4.70E+07	0.3928	3.72E+10	0.2072	7.70E+09
0.5	0.0020	3.283E+09	3.283E+09	0.4999999974	39.0	0.307861	1.033E-09	5.287E-09	4.22E+07	0.3079	3.73E+10	0.1921	7.16E+09
0.4	0.0025	2.101E+09	2.101E+09	0.3999999968	44.0	0.225097	1.219E-09	8.080E-09	3.56E+07	0.2251	3.71E+10	0.1749	6.49E+09
0.3	0.0030	1.459E+09	1.459E+09	0.2999999966	53.0	0.141108	1.083E-09	1.142E-08	3.55E+07	0.1411	3.29E+10	0.1589	5.22E+09
0.2	0.0050	5.252E+08	5.252E+08	0.1999999940	70.0	0.068218	1.439E-09	3.0042E-08	2.31E+07	0.0682	2.84E+10	0.1318	3.74E+09
0.1													
							Number of successful scattered deuteron targets =				1.05E+12		2.90E+11
							Average energy of the successful scattered deuteron targets =					0.2751	MeV

There are 1.05x10[12] energetic ^{2}d energized per second. The average final energy of the ^{2}d targets is 0.2751 MeV.

Calculate the scattering rate of energetic ^3T with ^2d

A	B	C	D	E	F	G	H	I	J	K	L	M	N
E_{pi} in MeV	For the energy in each row, Θ_{CM_min} in degrees, rounded.	The numerical integration of $P(\Theta)$, summed from Θ_{CM_min} to Θ_{CM_max}.	The numerical integration of $P(\Theta)*(E_{pf}/E_{pi})$, summed from Θ_{CM_min} to Θ_{CM_max}.	Expectation energy $E_{pf}(\Theta)$ in MeV, from Θ_{min} to Θ_{max}.	Lab reference frame angle, where successful scattering starts. Rounded.	The numerical integration of $P(\Theta)$, summed from $\Theta_{CM\_success}$ to Θ_{CM_max}.	Fraction of successful scatters after one collsion.	Fractional energy loss per collision	Average number of times, N, the projectile collides before falling to the next lower energy level.	Expectation value of E_{pf} for the successful scatterers only, in MeV.	Number of successful scatters.	Expectation energy E_{tf} for the ^2D targets, for successful scatters, in MeV.	Expectation energy E_{tf} for only the successful scatters times number of successful scatters
1.01	0.0017	4.5437E+09	4.5437E+09	1.009999996	15	8.434365	1.856E-09	4.269E-09	2.3307E+06	0.7553	3.699E+09	0.2547	9.42E+08
1	0.0017	4.5437E+09	4.5437E+09	0.999999996	15	8.434441	1.856E-09	4.269E-09	2.4679E+07	0.7478	3.917E+10	0.2522	9.88E+09
0.9	0.0019	3.6375E+09	3.6375E+09	0.899999995	16	7.548632	2.075E-09	5.277E-09	2.2319E+07	0.6574	3.960E+10	0.2426	9.61E+09
0.8	0.0021	2.9776E+09	2.9776E+09	0.799999995	17	6.444733	2.164E-09	6.385E-09	2.0912E+07	0.5635	3.870E+10	0.2365	9.15E+09
0.7	0.0024	2.2797E+09	2.2797E+09	0.699999994	18	5.550040	2.435E-09	8.233E-09	1.8725E+07	0.4749	3.898E+10	0.2251	8.77E+09
0.6	0.0028	1.6749E+09	1.6749E+09	0.599999993	20	4.395495	2.624E-09	1.104E-08	1.6522E+07	0.3813	3.707E+10	0.2187	8.11E+09
0.5	0.0034	1.1359E+09	1.1359E+09	0.499999992	22	3.537132	3.114E-09	1.595E-08	1.3987E+07	0.2967	3.724E+10	0.2033	7.57E+09
0.4	0.0042	7.4440E+08	7.4440E+08	0.399999990	24	2.769826	3.721E-09	2.381E-08	1.2081E+07	0.2175	3.843E+10	0.1825	7.01E+09
0.3	0.0056	4.1873E+08	4.1873E+08	0.299999988	28	1.826343	4.362E-09	4.104E-08	9.8790E+06	0.1373	3.684E+10	0.1627	5.99E+09
0.2	0.0084	1.8610E+08	1.8610E+08	0.199999982	35	0.869584	4.673E-09	8.822E-08	7.8566E+06	0.0625	3.139E+10	0.1375	4.31E+09
0.1	0.0168	9.9653E+06	9.9653E+06	0.099999863	41	0.320099	3.212E-08	1.367E-06	3.3680E+06	0.0170		Sum=	7.13E+10
							Number of successful scattered deuteron targets =				3.374E+11		
									Average energy of the successful scatters =			0.211 MeV	

There are 3.374x10[11] energetic ^2d energized per second. The average final energy of the ^2d targets is 0.211 MeV.

Calculate the scattering rate of energetic ^3He with ^2d

A	B	C	D	E	F	G	H	I	J	K	L	M	N
E_{pi} in MeV	For the energy in each row, Θ_{CM_min} in degrees, rounded.	The numerical integration of $P(\Theta)$, summed from Θ_{CM_min} to Θ_{CM_max}.	The numerical integration of $P(\Theta)*(E_{pf}/E_{pi})$, summed from Θ_{CM_min} to Θ_{CM_max}.	Expectation energy $E_{pf}(\Theta)$ in MeV, from Θ_{min} to Θ_{max}.	Lab reference frame angle, where successful scattering starts. Rounded.	The numerical integration of $P(\Theta)$, summed from $\Theta_{CM\_success}$ to Θ_{CM_max}.	Fraction of successful scatters after one collsion.	Fractional energy loss per collision	Average number of times, N, the projectile collides before falling to the next lower energy level.	Expectation value of E_{pf} for the successful scatterers only, in MeV.	Number of successful scatters.	Expectation energy E_{tf} for the ^2D targets, for successful scatters, in MeV.	Expectation energy E_{tf} for only the successful scatters times number of successful scatters
0.8175	0.0041	7.81156E+08	7.81156E+08	0.817499981	17	6.444657	8.250E-09	2.275E-08	9.5113E+05	0.5759	6.709E+09	0.2416	1.62E+09
0.8	0.0042	7.44401E+08	7.44401E+08	0.799999981	17	6.444657	8.658E-09	2.381E-08	5.6073E+06	0.5635	4.151E+10	0.2365	9.81E+09
0.7	0.0048	5.69932E+08	5.69932E+08	0.699999979	18	5.549964	9.738E-09	3.066E-08	5.0271E+06	0.4749	4.186E+10	0.2251	9.42E+09
0.6	0.0056	4.18725E+08	4.18725E+08	0.599999975	20	4.395419	1.050E-08	4.104E-08	4.4422E+06	0.3813	3.987E+10	0.2187	8.72E+09
0.5	0.0067	2.92520E+08	2.92520E+08	0.499999971	22	3.537056	1.209E-08	5.759E-08	3.8745E+06	0.2967	4.006E+10	0.2033	8.14E+09
0.4	0.0084	1.86100E+08	1.86100E+08	0.399999965	24	2.769750	1.488E-08	8.822E-08	3.2608E+06	0.2176	4.149E+10	0.1824	7.57E+09
0.3	0.0112	1.04681E+08	1.04681E+08	0.299999955	28	1.826266	1.745E-08	1.516E-07	2.6742E+06	0.1373	3.989E+10	0.1627	6.49E+09
0.2	0.0168	4.54368E+07	4.54368E+07	0.199999934	35	0.869508	1.914E-08	3.318E-07	2.0890E+06	0.0625	3.418E+10	0.1375	4.70E+09
0.1	0.0337	1.135919E+07	1.135918E+07	0.099999879	41	0.320023	2.817E-08	1.211E-06	8.7032E+04	0.0170	2.096E+09	0.0830	1.74E+08
												Sum=	5.67E+10
							Number of successful scattered deuteron targets =				2.877E+11		
									Average energy of the successful scatters =			0.197 MeV	

There are 2.877x10[11] energetic ^2d energized per second. The average final energy of the ^2d targets is 0.197 MeV.

Neutron Scattering:

- Neutron scattering is easier to determine.
  - There are tables, graphs, and much experimental data for scattering cross sections.
- For 2.45 MeV neutrons scattering with ^{2}d, the logarithmic energy decrement is 72.53 and the cross section 2.55 barns.
  - Average energy retained by the neutron after one scatter with ^{2}d is 1.188 MeV.
  - Average energy transferred to the ^{2}d is 1.265 MeV.
  - Only energy transfers over 0.1 MeV are considered.
- Using numbers in this example, the probability of this first successful scatter is:

$$P_{n\_to\_d} = (2.4\times10^{-24})(0.2)(6.8\times10^{23})$$

$$P_{n\_to\_d} = 0.289 \text{ or } 28.9\%$$

- This calculation is repeated with the new lower energy.
- Re-iterated and re-calculated for all neutrons still in the core.
- Repeated until the transferred energy drops below 0.1 MeV.
- The number of successful scatters for ^{2}d in the core is 1.512×10^{12}.
- The average energy of the successfully-scattered ^{2}d ions is 0.5859 MeV.

Understanding Reaction Rates

The reaction rate for fusion:

$$fusion_{rate} = (\rho_{target})(\sigma(E))(v_{projectile})(\rho_{projectile})$$

- The difficult parameter is the density of the projectile, $\rho_{projectile}$.
  - $\rho_{projectile}$ is the introduction rate x time spent at energy:

$$\rho_{projectile} = Rate_{intro} \times t_{at\ energy}$$

- The initial introduction rate is 8.55×10^{11} projectiles/sec.

$$t_{at\_energy} = \frac{Distance_{at\_one\_energy}}{v_{projectile}}$$

The velocity of the projectile cancels in the equation for the fusion rate, and we are left with:

$$fusion_{rate} = (\rho_{target})(\sigma(E))(Rate_{intro})(Distance_{at\_one\_energy})$$

- To calculate this distance, we need N_{ave}, the average number of times it scatters within the energy range:

$$N_{ave} = \frac{ln\left(\frac{E_{lower}}{E_{higher}}\right)}{ln(1 - fractional_{energy\_loss})}$$

- L_{ave} is one over of the cube root of the density of ^2D. $L_{ave} = {}^{1}/_{\left(\sqrt[3]{\rho_{target}}\right)}$

Reaction Rates for ^{3}t to ^{2}d

- The calculations for the distance traveled by the energized ^{3}T ion is shown to the right. This is for all angles, and all energies from 1.01 MeV to 0.01 MeV.
  - The distance L_{ave} is the average distance of the deuterons in the lattice. $L_{ave} = 2.45 \times 10^{-8}$ cm and is based on the density of the deuteron in the lattice.
  - At the right column of this table is the total distance traveled, in cm, within that energy range.
  - That value is used to determine the reaction rate for that one energy range.
- For ^{3}T to ^{2}D, the reaction the cross section is 3×10^{-26} at 0.01 MeV. We will use this value as the lower threshold, below which we will ignore the reaction rate as being too small to consider.

$Energy_{ip}$	v in m/s	Θ_{CM_min} in radians	Lab Final Projectile Energy, divided by the Initial Projectile Energy, for the Energy in Column A	N, number of scatters, on average, before losing energy below the next level, NOT taking the Pd into account.	Total distance traveled, L_{ave} x N, in cm.
1.01	8.0314E+06	2.9093E-05	0.999999999797	4.89833E+07	1.20
1	7.9915E+06	2.9384E-05	0.999999999793	4.85008E+07	1.19
0.99	7.9514E+06	2.9681E-05	0.999999999789	4.80182E+07	1.18
0.98	7.9112E+06	2.9984E-05	0.999999999784	4.75357E+07	1.16
0.97	7.8707E+06	3.0293E-05	0.999999999780	4.70531E+07	1.15
0.96	7.8300E+06	3.0608E-05	0.999999999775	4.65705E+07	1.14
0.95	7.7892E+06	3.0930E-05	0.999999999770	4.60880E+07	1.13
0.94	7.7481E+06	3.1260E-05	0.999999999765	4.56054E+07	1.12
0.93	7.7067E+06	3.1596E-05	0.999999999760	4.51229E+07	1.11
0.92	7.6652E+06	3.1939E-05	0.999999999755	4.46403E+07	1.09
0.91	7.6234E+06	3.2290E-05	0.999999999750	4.41577E+07	1.08
0.9	7.5814E+06	3.2649E-05	0.999999999744	4.36752E+07	1.07
(…)					
0.09	2.3975E+06	3.2649E-04	0.999999974417	4.60401E+06	0.11
0.08	2.2603E+06	3.6730E-04	0.999999967622	4.12412E+06	0.10
0.07	2.1144E+06	4.1977E-04	0.999999957710	3.64510E+06	0.09
0.06	1.9575E+06	4.8973E-04	0.999999942439	3.16744E+06	0.08
0.05	1.7870E+06	5.8768E-04	0.999999917112	2.69211E+06	0.07
0.04	1.5983E+06	7.3460E-04	0.999999870488	2.22127E+06	0.05
0.03	1.3842E+06	9.7947E-04	0.999999769756	1.76102E+06	0.04
0.02	1.1302E+06	1.4692E-03	0.999999481950	1.33799E+06	0.03

Continued--Reaction Rates

- Using these numbers for the total distance, we can then solve for the reaction rate.

$$fusion_{rate} = (\rho_{target})(\sigma(E))(Rate_{intro})(Distance_{at\_one\_energy})$$

- Using the numbers for 1.01 MeV: $fusion_{rate} = (6.800\times10^{22})(2.45\times10^{-25})(8.55\times10^{11})(1.20) = 1.71\times10^{10}$
- This is seen in the first row of the table below, where the reaction rate for ^{3}T + ^{2}D is calculated for each energy step. Particle loss by escape is reasonably estimated at 0.1%. For the numbers in this example, the total that react is $8.42\text{x}10^{11}$. This is 98.44%, as highlighted in green.

Energy of ^{3}T projectile, in MeV	Introduction rate of projectile ion, # per cm^3	projectile velocity at this energy, in cm/sec	The average total distance traveled, for this energy range, in cm	Average total time spent in core at this energy, in sec.	Density of projectile ion, in # per cm^3	Reaction cross section at this energy for $^{3}T+^{2}D$ reaction, in cm^2	Reaction rate, in $\#/cm^3$	Fractional of lost projectiles, by reaction	Estimated fraction of lost projectiles, by escape, set to 0.1%	Amount of ^{3}T remaining in core after one full collision cycle
1.01	8.55E+11	8.03E+08	1.20	1.49E-09	1.28E+03	2.45E-25	1.71E+10	0.020	0.001	8.37E+11
0.9	8.37E+11	7.58E+08	11.35	1.50E-08	1.25E+04	2.80E-25	1.81E+11	0.216	0.001	6.56E+11
0.8	6.56E+11	7.15E+08	10.17	1.42E-08	9.33E+03	3.20E-25	1.45E+11	0.221	0.001	5.10E+11
0.7	5.10E+11	6.69E+08	8.99	1.34E-08	6.85E+03	3.70E-25	1.16E+11	0.226	0.001	3.94E+11
0.6	3.94E+11	6.19E+08	7.80	1.26E-08	4.97E+03	4.60E-25	9.66E+10	0.244	0.001	2.98E+11
0.5	2.98E+11	5.65E+08	6.62	1.17E-08	3.49E+03	6.20E-25	8.35E+10	0.279	0.001	2.14E+11
0.4	2.14E+11	5.05E+08	5.44	1.08E-08	2.31E+03	8.30E-25	6.62E+10	0.307	0.001	1.48E+11
0.3	1.48E+11	4.38E+08	4.26	9.73E-09	1.44E+03	1.34E-24	5.80E+10	0.388	0.001	9.08E+10
0.2	9.08E+10	3.57E+08	3.08	8.61E-09	7.81E+02	2.60E-24	4.97E+10	0.544	0.001	4.14E+10
0.1	4.14E+10	2.53E+08	1.89	7.50E-09	3.10E+02	5.00E-24	2.69E+10	0.644	0.001	1.47E+10
0.09	1.47E+10	2.40E+08	0.11	4.70E-10	6.92E+00	4.60E-24	5.24E+08	0.035	0.001	1.42E+10
0.08	1.42E+10	2.26E+08	0.10	4.47E-10	6.34E+00	4.00E-24	3.94E+08	0.027	0.001	1.38E+10
0.07	1.38E+10	2.11E+08	0.09	4.22E-10	5.82E+00	3.20E-24	2.71E+08	0.019	0.001	1.35E+10
0.06	1.35E+10	1.96E+08	0.08	3.96E-10	5.35E+00	2.20E-24	1.59E+08	0.012	0.001	1.33E+10
0.05	1.33E+10	1.79E+08	0.07	3.69E-10	4.92E+00	1.40E-24	8.48E+07	0.006	0.001	1.32E+10
0.04	1.32E+10	1.60E+08	0.05	3.40E-10	4.50E+00	7.70E-25	3.82E+07	0.003	0.001	1.32E+10
0.03	1.32E+10	1.38E+08	0.04	3.12E-10	4.11E+00	3.00E-25	1.18E+07	0.001	0.001	1.31E+10
0.02	1.31E+10	1.13E+08	0.03	2.90E-10	3.81E+00	5.00E-26	1.49E+06	0.000	0.001	1.31E+10
						Sum =	8.42E+11	$\#/cm^2/sec$		
					Percentage of ^{3}T that reacts =		98.44	%		

Continued--Reaction Rates

Reaction Rates for ^3He + ^2d.

- This entire procedure is repeated for the ^3He to ^2D reaction.
- This table is similar to the previous table for ^3T and ^2D, (however, it is not shown).
- The percentage for this reaction is 41.59%.

- An additional 3.413 watts are generated from secondary reactions. Total power=4.413 W.
- There are four new secondary child products: ^4He, neutrons, more ^4He, and protons.
- The energy/^4He ratio of the Pd core is (4.413) / ($1.194x10^{12}$) = 23.1 MeV/^4He.

Experimentally, this heat to ^4He ratio can vary slightly, depending on: the exact size of the core, the apparatus set up, the number of escaped ions, and how many escaped neutrons there are through the apparatus, and how the calorimetry is measured experimentally.

Scattering of the Secondary Child Products.

- These 4 energetic child products also scatter with ^2D, like previous child products.
- The same equations and procedures apply. (The details are not repeated here.)
- The final results, for both the primary and secondary reactions are shown in the table, right.
- There are 8.26×10^{12} hot ^2D
- The gain in the number of energetic ^2D is 4.83.
- Average energy of 0.607 MeV.

A	B	C	D	E	F
Projectile	**Source of projectile**	**initial energy of projectile, in MeV**	**number of hot ^2D from this projectile**	**average energy for this hot ^2D, in MeV**	**number of hot ^2D multiplied by the average energy of the ^2D**
Proton	Primary1	3.03	1.05E+12	0.275	2.90E+11
T3	Primary1	1.01	3.41E+11	0.209	7.13E+10
neutron	Primary2	2.45	2.34E+12	0.599	1.40E+12
He3	Primary2	0.82	2.88E+11	0.197	5.67E+10
He4	Secondary1	3.52	1.27E+12	0.293	3.73E+11
neutron	Secondary1	14.07	3.09E+11	5.815	1.79E+12
He4	Secondary2	3.68	5.65E+11	0.297	1.68E+11
Proton	Secondary2	14.72	2.09E+12	0.408	8.52E+11
		Sum =	8.26E+12	Sum =	5.01E+12
		Gain in the number of hot 2D =			4.83
		Average energy of hot ^2D, in MeV =			0.607

Determination of a Self-Sustaining Reaction.

- The final step is to determine if a self-sustaining reaction can take place.
- To do this, we look at the subsequent ^{2}D-to-^{2}D reaction rate and determine if the subsequent reaction rate for the next generation of $^{2}D+^{2}D$ reaction is greater than or less than the previous reaction rate.
- If so, the reactor can self-sustain its own reactions and it will release a net positive energy.
- If not, the the reactor can not self-sustain it's own reactions, and the reactions will quickly end.
- That determination for the next generation of subsequent reactions is made in the table below.

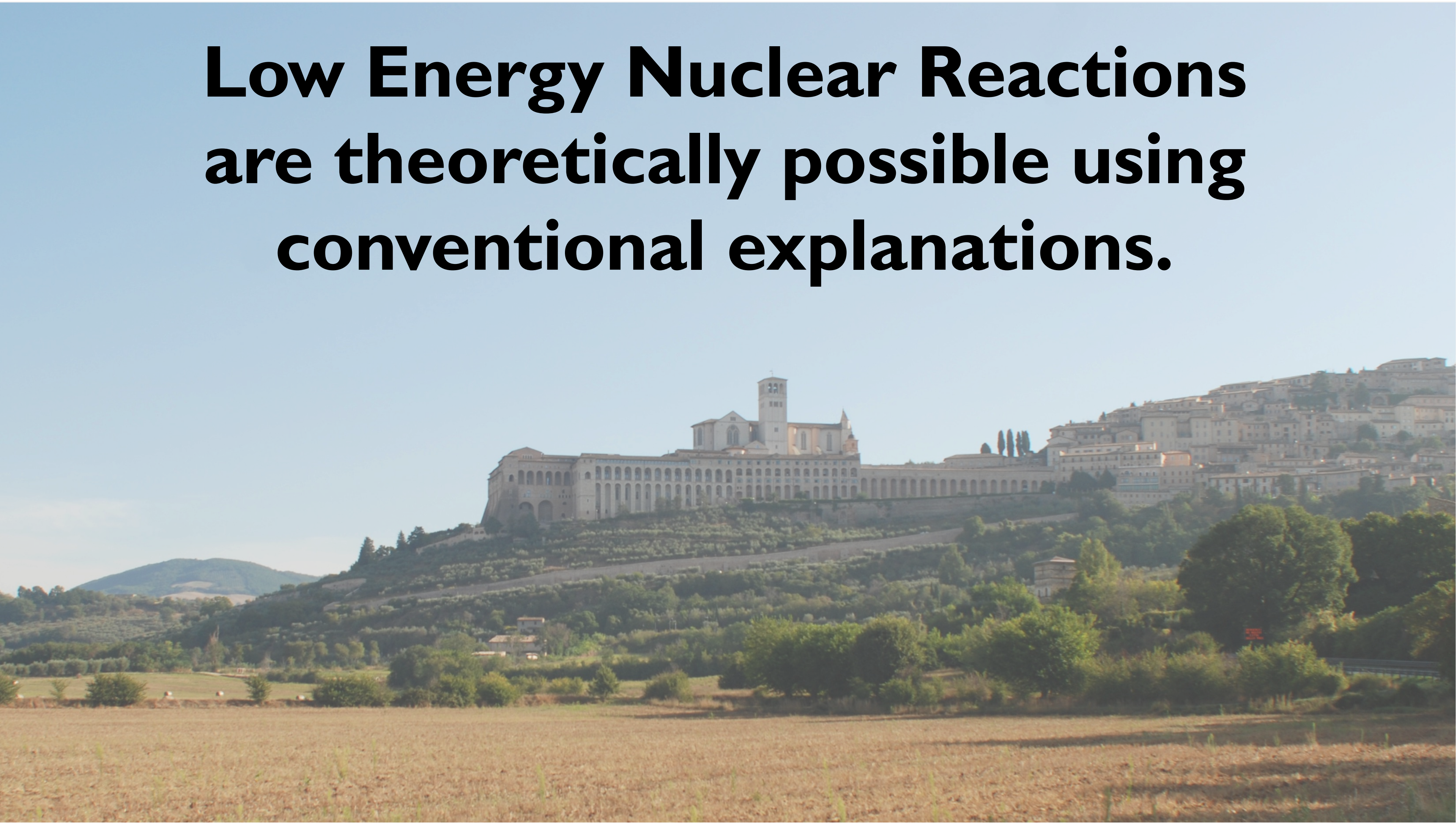
A	B	C	D	E	F	G	H
Energy range of projectile ion in MeV	**Introduction rate of projectile ion in #/cm^3/sec**	**Average total distance travelled before the energy drops to next level, in cm.**	**Reaction cross section at this energy, in sq. cm.**	**Reaction rate at this energy**	**The fraction of the lost projectiles due to reaction.**	**The fraction of the lost projectiles due to escape.**	**Amount of D-2 remaining in lattice after the energy drops to next level. (This is the introduction rate for the next lower energy level.)**
0.6066	8.26E+12	3.33	1.61E-25	3.00E+11	0.0364	0.001	7.95E+12
0.60	7.95E+12	5.56	1.60E-25	4.80E+11	0.0604	0.001	7.46E+12
0.55	7.46E+12	3.83	1.54E-25	3.00E+11	0.0401	0.001	7.15E+12
0.50	7.15E+12	3.67	1.48E-25	2.64E+11	0.0369	0.001	6.88E+12
0.45	6.88E+12	3.33	1.39E-25	2.17E+11	0.0315	0.001	6.66E+12
0.40	6.66E+12	3.00	1.30E-25	1.77E+11	0.0265	0.001	6.48E+12
0.35	6.48E+12	2.77	1.18E-25	1.44E+11	0.0222	0.001	6.33E+12
0.30	6.33E+12	2.51	1.06E-25	1.14E+11	0.0181	0.001	6.21E+12
0.25	6.21E+12	2.28	8.90E-26	8.54E+10	0.0138	0.001	6.11E+12
0.20	6.11E+12	2.08	7.20E-26	6.21E+10	0.0102	0.001	6.05E+12
0.15	6.05E+12	1.96	5.2E-26	4.18E+10	0.0069	0.001	6.00E+12
0.10	6.00E+12	2.04	3.2E-26	2.66E+10	0.0044	0.001	5.97E+12
			Sum of reaction rate =	2.21E+12	subsequent reactions/sec		

- We need 1.71×10^{12} or more.
- We get 2.21×10^{12}.
- This reactor is able to a maintain a self-sustaining reaction!

Conclusions

- All the so-called “miracles” of LENR are explained.
  - ✓ The Coulomb barrier is overcome by the transference of kinetic energy to the cold ^{2}D.
  - ✓ Neutrons are emitted from the reactions, but very few escape the apparatus set-up.
  - ✓ Very little gamma radiation occurs, since neither the primary nor secondary reactions create them.
  - ✓ The predicted energy per ^{4}He ratio is right on target.
- No strange, unusual, or unconventional physics is needed.
- Simply apply normal nuclear engineering calculations to the LENR.
- What is new in this calculation, which have never previously been considered:
  - There are primary and secondary reactions in the palladium core.
  - The lattice-assistance provided by the PdD_x lattice.
  - Specifically the reduction of the electron stopping at the energies involved.
- The conclulsion is:
  - Yes, Low-Energy Nuclear Reactions are possible.

Low Energy Nuclear Reactions are theoretically possible using conventional explanations.



How can we test this experimentally:

- Measure the neutron flux from a running reactor, using no moderator.
- While the reactor is running in steady state, drain out the water from the water bath and the electrolyte.
- Also remove any hydrogen-containing materials, like polymers or insulation.
- Re-measure the neutrons coming out of the set-up with no water, and no moderator tube. The neutron count should increase significantly.

Why are Low Energy Nuclear Reactors so intermittent?

1. Start up.
   - Reactors need a start up mechanism. Otherwise it is at the mercy of random external influences. (Sunspots, Radon, Cosmic rays, etc.)
   - A well-shielded reactor, with lots of water and lead around it, will not start.
   - Put some Am-241or U-238 inside the core.

2. The high ^{2}D density within the lattice is difficult to obtain, causing frequent failures. This is an <u>excellent</u> place where more experimental research is needed, to determine how best to achieve this high density.

Why is no gamma radiation coming out of the reactor?

1. The primary and secondary reactions do not emit gamma radiation.

2. One reaction that creates gamma radiation is the Pd-105 + $n_{thermal}$ → Pd-106 + γ. However, this reaction will be small, since there are not many thermal neutrons in the Pd core.

3. The $^{1}H + n \rightarrow {}^{2}H + \gamma$ reaction creates a lot of gamma. Some of it is shielded by the apparatus. Also, not all of the neutrons react with the ^{1}H. The amount of gamma energy coming out of the reactor is much less, as a result.

4. The energy of the gamma from this reaction is too high for the usual or typical gamma detectors to detect, even for NaI detectors. Special detectors are needed, and they need to be calibrated.

Why is there <u>not</u> a lot of ^{3}He?

- Because of this reaction:
  - ^{3}He+n → ^{3}t+p.
  - Cross section is **5330** barns for thermal neutrons.
  - Even for 1 MeV neutrons, it is high.
- However, this reaction does not release much energy at all.
  - Thus, the child products are not energetic enough to increase the number of successful scattering events.
  - Nor does it add much to the overall energy output of the reactor.
  - Nor does it increase the percentage of the ^{3}T to ^{2}D reactions.
- Also, this reaction occurs when the density of ^{3}He is high enough.
  - When the reactor has been running in steady state for several hours.
  - This reaction only occurs when the reactor is already in a self-sustaining mode.
  - This reaction doesn't help to establish the self-sustaining mode.
- About the only thing it *does* do…is to change the ^{3}He into ^{3}H.

What about voltages?
For the steady state of an LENR reactor, the incoming flow of ^{2}D must be enough to sustain the reaction. You will need enough current and voltage for that.

For the loading process, the voltage matters, but the optimum voltage is unknown. Again, this needs to be researched. What voltage makes the densest ^{2}D? The details of the loading process are in need of more research and documentation.