Nuclear signatures to be expected from Rossi energy amplifier

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Abstract: the nuclear signatures that can be expected when contacting hydrogen with fine nickel powders are derived from thermal results recently obtained (Rossi energy amplifier). The initiation of the reactions (either by proton or neutron capture) is not discussed and considered as true. Proposals are made to check the process either by radiation emission measurements or by elemental analysis (ICP-MS)

1/ Introduction:

In a recent paper [1], results are presented on vast amounts of energy (kWh) generated by contacting Hydrogen at pressures of tens of bars and temperatures round 400°C, with nickel powder (with an unspecified additive). No harmful radiations were measured, which is attributed to the presence of a lead shield absorbing γ emission occurring during the run and to the very short period of the instable species formed during the run and decaying after shut down. The efficiency of the process is very high (E_{out}/E_{in} up to 400). These levels of energy production strongly points to a nuclear origin. The proposed process [1] would be proton capture by the nickel nuclei.
The coulomb barrier problem is suggested to be solved by the strong screening of the electrons. Another solution has been proposed [2]: virtual neutrons formation, reacting with the Nickel nuclei. This solution is also proposed in [3] with a very elaborate justification.
In this paper, the capture of a neutron or a proton by a nickel nucleus is accepted as real. The consequences of these captures are analyzed (using very well documented nuclear chemistry data [4], [5]) and proposals are made for precise verification of the process invoked.

2/ The neutron or proton capture by Nickel:

The reactions paths for these 2 routes finally ends up to the same stable products (^{59}Co, ^{61}Ni, ^{62}Ni, ^{63}Cu and ^{65}Cu) and are summarized in ***Table 1*** and ***2*** below.

Table 1

NEUTRON CAPTURE							
Ni parent isotopic composition	Ni parent nucleus	Mass parent or daughter Ni nucleus	Energy (MeV) released	Excited intermediate nucleus	Decay intermediate nucleus ground state	End stable nucleus	Natural copper isotopic composition
0.68007	^{58} Ni	57.935346	8.22	^{59} Ni*	EC, 7.5 10^4 y, 1.07	^{59} Co	
	^{59} Ni	58.934349					
0.26223	^{60} Ni	59.930788	7.04	^{61} Ni*		^{61} Ni	
0.0114	^{61} Ni	60.931058	9.82	^{62} Ni*		^{62} Ni	
0.03634	^{62} Ni	61.928346	6.06	^{63} Ni*	β^-, 100 y, 0.066	^{63} Cu	0.6917
	^{63} Ni	62.929669					
0.00926	^{64} Ni	63.927968	5.32	^{65} Ni*	β^-, 2.52h, 2.14	^{65} Cu	0.3083
	^{65} Ni	64.930086					

The energy release (see ***Table 3***) occurs mostly by de-excitation through γ emission of the intermediate excited Ni* compound nucleus. The characteristics of this γ emission (depending upon the levels of the excited nucleus), are very well known [4]. This represents (on average) some 8 MeV (balance after deduction of the energy required for the "virtual neutron" formation, i.e 0,782 Mev). The remaining comes from the decay of the ground states of the radioactive intermediate species formed (^{59}Ni, ^{63}Ni, and ^{65}Ni). Data for intermediate radioactive species are from [5].

Table 2

PROTON CAPTURE								
Ni parent isotopic composition	Ni parent nucleus	Mass parent Ni nucleus	Mass daughter Cu nucleus	Energy (MeV) released	Excited intermediate nucleus	Decay intermediate nucleus ground state	End stable nucleus	Natural copper isotopic composition
0.68007	^{58}Ni	57.935346		3.42	^{59}Cu*	β^+, 82s, 4.8	^{59}Ni = ^{59}Co	see note (1)
	^{59}Ni		58.939503					
0.26223	^{60}Ni	59.930788		4.8	^{61}Cu*	β^+, 3.41h, 2.34	^{61}Ni	
0.0114	^{61}Ni	60.931058	60.933461	5.87	^{62}Cu*	β^+, 9.73mn, 3.92	^{62}Ni	
0.03634	^{62}Ni	61.928346	61.932586	6.12	^{63}Cu*		^{63}Cu	0,6917
	^{63}Ni		62.929598					
0.00926	^{64}Ni	63.927968		7.45	^{65}Cu*		^{65}Cu	0,3083
	^{65}Ni		64.927793					
(1) ^{59}Ni from ^{59}Cu decays to ^{59}Co by electron capture (life time 7.5 10^4 y)								

The energy is released in a way very similar to the neutron capture route, with a lower release from the de-excitation of the intermediate excited Cu* compounds nucleus (some 4 MeV, see ***Table 3***). The remaining half comes from the decay of the ground states of the radioactive intermediate species formed (^{59}Cu, ^{59}Ni, ^{61}Cu and ^{62}Cu). Data for intermediate radioactive species are from [5].

3/ Evaluation of the reaction rates:

One experiment (Type B) presented in [1], has yielded 3768 kWh for an energy input of 18.54 kWh (between March 5, 2009 and April 26, 2009). This is a net power produced of some 3 kW during some $4.5*10^6$ seconds.

From ***Table 1*** and ***2***, the energy released per Ni atom (averaged by the isotopic composition of the Nickel) has been calculated under following hypothesis:

- the captures (proton or neutron) have the same probabilities whatever the Ni isotope is. This is a first approximation. For the neutron capture route, following cross sections (barn) are measured: ^{58}Ni:4.6, ^{60}Ni:2.9, ^{61}Ni:2.5, ^{62}Ni:15 and ^{64}Ni:2.9).
- the subsequent reactions with formed products are not taken into account (too low concentration to have any significant effect).
- decay energy of nucleus with half life time much longer than the experiment duration have been ignored (^{59}Ni for the proton route and ^{59}Ni, ^{63}Ni for the neutron route)

Table 3 below is thus obtained.

ENERGY RELEASED (MeV)		
	Neutron capture	Proton capture
De-excitation	7.82	3.94
Decay	0.02	3.92
TOTAL	7.84	7.86

As expected, the 2 routes give similar amounts of energy, mainly de-excitation for the neutron route and half de-excitation, half decay for the proton route.

The proton or neutron capture rate can thus be evaluated as:

$$r = \frac{3000}{7.85 * 1.6\ 10^{-13}} = 2.4\ 10^{15}\ \ s^{-1} \qquad \text{for both routes}$$

4/ Evaluation of the γ emission rates:

The de-excitation of a compound nucleus resulting from neutron capture is very well documented [4]. For nickel, 1 capture gives rise to 2.66 emission of γ photon, with an energy repartition f_i given by ***Table 4***:

Table 4

NEUTRON CAPTURE			
	γ Energy MeV	Repartition (f_i)	Absorption coefficient μ cm^{-1}
	0.5	0.32	0.578
	1.5	0.15	0.045
	2.5	0.09	0.0229
	4	0.09	0.024
	6	0.13	0.0398
	8	0.22	0.079
Mean value	3.58	1.0	

Table 5

PROTON CAPTURE			
	γ Energy MeV	Repartition (f_i')	Absorption coefficient μ cm^{-1}
	0.25	0.18	1.136
	0.75	0.51	0.139
	1.25	0.05	0.058
	2	0.05	0.045
	3	0.07	0.061
	4	0,14	0.111
Mean value	1.79	1.0	

For the proton capture route, less data are available. To get a first order of magnitude of the γ emission coming from the de-excitation of the primary nucleus formed, the same number of photons per proton capture with the same energy repartition as for the nickel has been taken into account, with of course an average value half the one for nickel (1.79 MeV compared to 3.58). The second half of the energy comes (in the form of γ photons) from the short live β+ emitters: associated γ emission, bremsstrahlung of the positron and annihilation radiation. The average energy of these photons is taken to be in the 0.75 MeV range, thus less penetrating. The energy repartitions f_i' (***Table 5***), have been evaluated according to the photon production rate in the proton capture route given below.

Finally, the γ photon production rate r_γ for both routes has been evaluated as follows:

-Neutron capture route $\left(r_\gamma\right)_N = 2.66r$

-Proton capture route $\left(r_\gamma\right)_p = 2.66r\left(0.5+\dfrac{0.5*\left(E_\gamma\right)_{\beta^+}}{2.66*0.75}\right) = 2.66r\left(0.5+0.9825\right)$

$\left(E_\gamma\right)_{\beta^+}$ being the mean energy released by the β+ emissions (3.92 MeV)

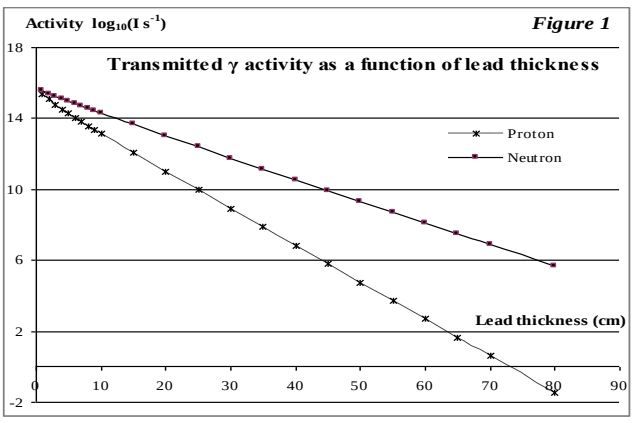
5/ Effect of lead shielding on expected γ emission:

For a poly-energetic beam of photons, the attenuation I/I_0, resulting from a thickness *d* of lead, is:

$I/I_0 = \sum_i f_i \exp\left(-d\mu_i\right)$ f_i is the fraction of the beam of energy E_i and μ_i the absorption coefficient for photons of energy E_i (cm^{-1} with d *cm*).

In [6], the quantity μ/ρ (cm^2/g) is given for photon energies from 1eV to 20 MeV. This gives for lead (ρ=*11.34 g.cm*$^{-3}$), the absorptions coefficients μ_i (tables 4 and 5)

Finally, following relations were used to evaluate the attenuation of the beam for increasing values of d (f_i from table 4 and f_i' from table 5):



Neutron capture route $\dfrac{I}{I_0} = \sum_i f_i \exp\left(-d\mu_i\right)$

Proton capture route $\dfrac{I}{I_0} = \sum_i f_i' \exp\left(-\mu_i d\right)$

Figure 1 gives the transmitted γ activity (as $\log_{10}(I.s^{-1})$, as a function of the lead thickness d.

As expected, the lead shielding is more efficient in the proton capture route. Even in that case and for 40 cm of lead, the transmitted activity is still 10^6 s^{-1}. The corresponding value is $3*10^{10}$ s^{-1} in the neutron capture route.

An important point must be stressed: in the above calculation, the emitting nuclear source is considered to be concentrated in one single point, which is of course not the case. To get a realistic evaluation of the expected flux of photons, it is supposed that the Nickel powder is contained in a cylindrical reactor, diameter 2 cm and length 100 cm (Outer surface 628 cm2). At 1 meter from this tube, shielded by 40 cm of lead, the photons flux is thus ≈1 $s^{-1}cm^{-2}$ for proton capture and ≈ $5*10^3$ $s^{-1}cm^{-2}$ for neutron capture.

6/ Final products and residual activity after shut down:

The number of stable atoms *i* formed at the end of the experiment (time *T*) is:

$$N_i(T) = r_i T = r x_i T$$

For radioactive atoms with a disintegration constant λ_i, the number of atoms formed at *T* is:

$$N_i(T) = \frac{r x_i}{\lambda_i}\left(1 - e^{-\lambda_i T}\right)$$

For short life atoms ($^{59,61 \text{ and } 62}$Cu-proton capture- ^{65}Ni-neutron capture-), the asymptotic limit is reached well before *T* and the number of atoms at *T* is:

$$N_i(T) = \frac{r x_i}{\lambda_i}$$

For long life atoms ($^{59 \text{ and } 63}$Ni-neutron capture and ^{59}Ni-proton capture), the final product at T can be considered to be $^{59 \text{ and } 63}$Ni on the one hand and ^{59}Ni on the other.

Table 6 and ***7*** summarize the various atoms formed at the experiment shut-down.

Table 6

NEUTRON CAPTURE						
Ni parent composition xi	Intermediate ground state nucleus	Disintegration constant λ (s-1)	Intermediate ground state atoms at T	First (or final) daughter nucleus	Stable atoms formed at T (^{59}Ni and ^{63}Ni are "quasi-stable": they decay slowly to ^{59}Co and ^{63}Cu)	
0.68007	^{59}Ni	$2.90\ 10^{-13}$	$7.32\ 10^{21}$	^{59}Co	^{59}Ni	$7.32\ 10^{21}$
0.26223	^{61}Ni				^{61}Ni	$2.82\ 10^{21}$
0.0114	^{62}Ni				^{62}Ni	$1.23\ 10^{20}$
0.03634	^{63}Ni	$2.20\ 10^{-11}$	$3.91\ 10^{20}$	^{63}Cu	^{63}Ni	$3.91\ 10^{20}$
0.00926	^{65}Ni	$7.64\ 10^{-5}$	$2.90\ 10^{17}$	^{65}Cu	^{65}Cu	$9.97\ 10^{19}$

Table 7

PROTON CAPTURE						
Ni parent composition xi	Intermediate ground state nucleus	Disintegration constant λ (s-1)	Intermediate ground state atoms at T	First (or final) daughter nucleus	Stable atoms formed at T (^{59}Ni is "quasi-stable" and decays slowly to ^{59}Co)	
0.68007	^{59}Cu	$8.45\ 10^{-3}$	$1.93\ 10^{17}$	^{59}Ni	^{59}Ni	$7.30\ 10^{21}$
0.26223	^{61}Cu	$5.65\ 10^{-5}$	$1.11\ 10^{19}$	^{61}Ni	^{61}Ni	$2.81\ 10^{21}$
0.0114	^{62}Cu	$1.19\ 10^{-3}$	$2.3\ 10^{16}$	^{62}Ni	^{62}Ni	$1.22\ 10^{20}$
0.03634	^{63}Cu				^{63}Cu	$3.90\ 10^{20}$
0.00926	^{65}Cu				^{65}Cu	$9.94\ 10^{19}$

7/ Residual activity after shut down:

For both routes, short live species are formed: ^{65}Ni for neutron capture and $^{59,61\ and\ 62}$Cu for proton capture.

(see ***Tables 1,2,6*** and ***7***). Their concentrations at shut down Ni(T) are given in Table 6 and 7. Their activity decreases as $N_i(t) = N_i(T)e^{-\lambda_i t}$ (t=0 at shutdown). Table 8 gives Ni(T) at shutdown (after duration T of the experiment) and the remaining atoms at t=7200 s (2 hour after shut down) $N_i(7200) = N_i(T)e^{-7200\lambda_i}$ and hence the residual activity at that time $\frac{dN_i(7200)}{dt} = -\lambda_i N_i(7200)$ (s^{-1}).

Table 8 and 9 below give the residual activity 2 hours after shutdown. The energy of the main characteristic gammas are given in keV and the branching ratios in % (between brackets).

Table 8

NEUTRON CAPTURE						
Ni parent composition xi	Intermediate ground state nucleus	Disintegration constant λ (s-1)	Ni(T) (atoms)	Ni(7200) (atoms)	Acivity after 2 hours dNi/dt (s-1)	Main gamma photons keV, (%)
0.68007	^{59}Ni	$2.90x10^{-13}$	$7.32x10^{21}$	$7.32x10^{21}$	$2.15x10^{9}$	
0.26223	^{61}Ni					
0.0114	^{62}Ni					
0.03634	^{63}Ni	$2.20x10^{-11}$	$3.91x10^{20}$	$3.91x10^{20}$	$8.6x10^{9}$	
						1481, (23)
0.00926	^{65}Ni	$7.64x10^{-5}$	$2.90x10^{17}$	$1.68x10^{17}$	$1.28*10^{13}$	1115, (14)
						366, (4,6)

Table 9

PROTON CAPTURE						
Ni parent composition xi	Intermediate ground state nucleus	Disintegration constant λ (s^{-1})	Ni(T) (atoms)	Ni(7200) (atoms)	Acivity after 2 hours dNi/dt (s^{-1})	Main gamma photons keV, (%)
0.68007	^{59}Cu	$8.45x10^{-3}$	$1.93x10^{17}$	$7.13x10^{-10}$	$6.03x10^{-12}$	511, (196)
0.26223	^{61}Cu	$5.65x10^{-5}$	$1.11x10^{19}$	$7.41x10^{18}$	$4.19x10^{14}$	511, (122)
0.0114	^{62}Cu	$1.19x10^{-3}$	$2.3x10^{16}$	$4.46x10^{12}$	$5.3x10^{9}$	511, (196)
0.03634	^{63}Cu					
0.00926	^{65}Cu					

It can be seen from ***Table 8*** (neutron capture), that 2 hours after shutdown, the activity of ^{65}Ni is still $1.3x10^{13}$ s^{-1}. For proton capture (***Table 9***) the corresponding activity of ^{61}Cu is still $4.2x10^{14}$ s^{-1}.

As for the emission during the run, the emitting nuclear source is considered to be concentrated in one single point, which is of course not the case. If, as supposed previously, the Nickel powder is contained in a cylindrical reactor, diameter 2 cm and length 100 cm, the total weight of nickel is some 1260g (apparent density 4, volume 300 cm3). If 3 cm3 of the powder is placed against a germanium detector, the activity would be reduced to some $10^{11}/10^{12}$ s^{-1} and characteristic radiations could be measured (annihilation radiation for ^{61}Cu and characteristic gammas (see ***Table 8***) for ^{65}Ni).

8/ Transmuted products formed:

If the total amount of nickel supposed to be processed is some 1260g, corresponding to 21,7 mole or $1.30x10^{25}$ atoms, a tentative mass balance can be made.

For both routes, the isotopic composition of the Nickel is not significantly altered. For both routes, a sizeable amount of "quasi stable" ^{59}Ni is produced, that represent more than 500 ppm atoms of the starting nickel. This is far beyond the precision of Mass spectrometry and could thus be easily detected. In the neutron capture route, "quasi-stable" ^{63}Ni could also be detected (50 ppm atoms).

As regards the isotopic ratio of copper $^{63}Cu/_{65}Cu = 2.244$, it should increase in the proton capture route (the copper produced has a ratio of 3.92). It should decrease in the neutron capture route (no ^{63}Cu is produced). The copper produced represents some 7 ppm atoms in the neutron route and some 37 ppm atom in the proton route. Starting from Nickel powder containing round 1 ppm Copper should give reliable indications on the process.

9/ Conclusion:

Strong nuclear signatures are expected from the Rossi energy amplifier and it is hoped that this note can help evidence them.

It is of interest to note that in [3] a mechanism is proposed, that strongly suppresses the gamma emission during the run (it is the same mechanism that creates very low energy neutrons, subsequently captured by the nickel. This does not suppress the emission after shut-down, which should be observed, together with the transmutations described above.

References

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