Hydrogen Embrittlement, Microcracking, and Piezonuclear Fission Reactions at the Ni and Pd Electrodes of Electrolysis “Cold Fusion” Experiments

A. Carpinteri, O. Borla, A. Goi, A. Manuelli, D. Veneziano

Department of Structural, Geotechnical and Building Engineering Politecnico di Torino, Italy
CHARACTERISTIC PHENOMENA IN THE SO-CALLED COLD FUSION (CF)

- 1989 - Fleishman & Pons → Heat Generation
- 1998 - Mizuno → Heat Generation
  Neutron Emission
  Compositional changes
- 2008 - Mosier-Boss et al. → Heat Generation
  Neutron Emission
  Compositional changes
  Alpha particle emissions

Fleischmann, Pons, Hawkins, 1989. J. Electroanalitical Chemistry
Cold Fusion vs Piezonuclear Reactions

“A unified interpretation and theory of these phenomena has not been accepted and their comprehension still remains unresolved” (Preparata 1991)

Is there a relation between the experimental evidence of the so-called “Cold Fusion”, observed during the last two decades, and the Piezonuclear evidence recently observed from fracture of inert and nonradioactive materials?

Phenomena in common:

- Neutron Emission
- Alpha Emission
- Compositional Changes
- Micro-cracking and Fracture
Part I: Ni-Fe and Co-Cr Electrodes
Experimental Set-up

Electrolytic Cell

Co-Cr (D=3mm)  Ni-Fe (D=3mm)

Electrodes
Neutron Emissions

Instantaneous Neutron Emissions between 4 and 10 times the background level
Alpha Particle Emissions

CELL OFF: 0.015 Cs$^{-1}$ (mean value)

Total acquisition time: 1 hour
Alpha Particle Emissions

CELL ON: 0.030 Cs$^{-1}$ (mean value)

Total acquisition time: 1 hour
Cumulative Curves for the Alpha Emissions

![Graph showing cumulative alpha counts over time for a cell on and off.](image-url)

- **Time (sec)**: The x-axis represents time in seconds, ranging from 0 to 3500.
- **Cumulative alpha counts**: The y-axis represents the cumulative alpha counts, ranging from 0 to 12.
- **Cell On**: The black line represents the cumulative counts when the cell is on.
- **Cell Off**: The gray line represents the cumulative counts when the cell is off.

The graph indicates a higher cumulative count for the cell on compared to the cell off, suggesting a difference in emissions when the cell is active.
Ni-Fe Electrode: Compositional Changes

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Ni</th>
<th>Si</th>
<th>Mg</th>
<th>Fe</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 0 h</td>
<td>43.9%</td>
<td>1.1%</td>
<td>0.1%</td>
<td>30.5%</td>
<td>-</td>
</tr>
<tr>
<td>After 4 h</td>
<td>43.6%</td>
<td>0.5%</td>
<td>0.4%</td>
<td>30.7%</td>
<td>-</td>
</tr>
<tr>
<td>After 32 h</td>
<td>35.2%</td>
<td>5.0%</td>
<td>0.2%</td>
<td>27.9%</td>
<td>-</td>
</tr>
<tr>
<td>After 38 h</td>
<td>35.3%</td>
<td>1.5%</td>
<td>4.8%</td>
<td>27.3%</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

\[
\text{Ni} (-8.6\%) = \text{Si} (+3.9\%) + \text{Mg} (+4.7\%)
\]

\[
\text{Ni}_2^\text{58} \rightarrow 2\text{Si}_{14}^\text{28} + 2n
\]

\[
\text{Ni}_2^\text{58} \rightarrow 2\text{Mg}_{12}^\text{24} + 2\text{He}_2^4 + 2n
\]
## Ni-Fe Electrode: Compositional Changes

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**Ni (-8.6%) = Si (+3.9%) + Mg (+4.7%)**

\[
\text{Ni}_{28}^{58} \rightarrow 2\text{Si}_{14}^{28} + 2n
\]

**Fe (-3.2%) = Cr (+3.0%)**

\[
\text{Fe}_{26}^{56} \rightarrow \text{Cr}_{24}^{52} + \text{He}_2^4
\]
Co-Cr Electrode: Compositional Changes

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Co (%)</th>
<th>Fe (%)</th>
<th>Cr (%)</th>
<th>K (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 0 h</td>
<td>44.1%</td>
<td>3.1%</td>
<td>17.8%</td>
<td>0.5%</td>
</tr>
<tr>
<td>After 4 h</td>
<td>43.7%</td>
<td>1.6%</td>
<td>17.8%</td>
<td>2.2%</td>
</tr>
<tr>
<td>After 32 h</td>
<td>20.6%</td>
<td>26.3%</td>
<td>9.7%</td>
<td>12.9%</td>
</tr>
</tbody>
</table>

Co\(^{(-23.5\%)}\) = Fe\(^{(+23.2\%)}\)

\(\text{Co}\^{59}_{27} \rightarrow \text{Fe}\^{56}_{26} + \text{H}_1^1 + 2n\)
Co-Cr Electrode: Compositional Changes

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<td>20.6%</td>
<td>26.3%</td>
<td>9.7%</td>
<td>12.9%</td>
</tr>
</tbody>
</table>

Co (−23.5%) = Fe (+23.2%)

\[
\text{Co}_{27}^{59} \rightarrow \text{Fe}_{26}^{56} + \text{H}_1 + 2n
\]

Cr (−8.1%) + K$_2$CO$_3$ (−4.3%) = K (+12.4%)

\[
\text{Cr}_{24}^{52} \rightarrow \text{K}_{19}^{39} + 2\text{He}_2^4 + \text{H}_1 + 4n
\]
Co-Cr electrode surface BEFORE the test
Co-Cr electrode surface AFTER the test

Micro-cracking after 38 hours
Part II: Pd and Ni Electrodes
Experimental Set-up

Electrolytic Cell

Electrodes

Pd (D=3mm)

Ni-Fe (D=3mm)
Neutron Emission

Neutron Emissions between 3 and 7 times the background level.
PALLADIUM ELECTRODE
Palladium (−28.7%)
Iron (+2.0)

- After electrolysis

Concentration (mass %)

Analysis

M=2.0
σ=1.0
Calcium (+0.2)

![Graph showing calcium concentration (mass%) after electrolysis with analysis points marked.](image)
Oxygen (+18.5)
Magnesium (+1.0)

- After electrolysis

- Concentration (mass%)

- Analysis

- $M=1.0$

- $\sigma=0.9$
Potassium (+1.5)

![Graph showing the concentration of potassium after electrolysis. The graph includes a horizontal line labeled M=1.5 and another labeled σ=1.1, indicating the mean and standard deviation, respectively.]
Silicon (+1.1%)
Element concentrations before and after the Electrolysis

<table>
<thead>
<tr>
<th>Mean Values</th>
<th>Pd</th>
<th>Fe</th>
<th>Ca</th>
<th>O</th>
<th>Mg</th>
<th>K</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 0 hours (%)</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>After 20 hours (%)</td>
<td>71.3</td>
<td>2.0</td>
<td>0.2</td>
<td>18.5</td>
<td>1.0</td>
<td>1.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>

FIRST GENERATION REACTION (assumed)

\[
Pd_{106}^{46} \rightarrow Ca_{20}^{40} + Fe_{26}^{56} + 10 \text{ neutrons} \tag{1}
\]

\[\text{Pd}(-28.6\%) = \text{Ca} (+10.8\%) + \text{Fe} (+15.1\%) + \text{neutrons} (+2.7\%)\]
SECOND GENERATION REACTIONS

\[ \text{Fe}^{56}_{26} \rightarrow 3\text{O}^{16}_8 + \text{He}^{4}_2 + 4 \text{neutrons} \] (2)

\[ \text{Fe} (-15.1 \%) = \text{O} (+12.9 \%) + \text{He} (+1.1 \%) + \text{neutrons} (+1.1) \]
SECOND GENERATION REACTIONS

(2) \[ \text{Fe}^{56}_{26} \rightarrow 3\text{O}^{16}_{8} + \text{He}^{4}_{2} + 4 \text{ neutrons} \]

Fe (−15.1 %) = O (+12.9 %) + He (+1.1 %) + neutrons (+1.1)

(3) \[ \text{Ca}^{40}_{20} \rightarrow 2\text{O}^{16}_{8} + 2\text{He}^{4}_{2} \]

Ca (−5.9 %) = O (+4.7 %) + He (+1.2 %)
**SECOND GENERATION REACTIONS**

\[
\text{Fe}^{56}_{26} \rightarrow 3\text{O}^{16}_{8} + \text{He}^4 + 4\text{neutrons} \quad (2)
\]

\[
\text{Fe} (-15.1 \%) = \text{O} (+12.9 \%) + \text{He} (+1.1 \%) + \text{neutrons} (+1.1)
\]

\[
\text{Ca}^{40}_{20} \rightarrow 2\text{O}^{16}_{8} + 4\text{H}_1^1 + 4\text{neutrons} \quad (3)
\]

\[
\text{Ca} (-5.9 \%) = \text{O} (+4.7 \%) + \text{H} (+0.6 \%) + \text{neutrons} (+0.6 \%)
\]

\[
\text{Ca}^{40}_{20} \rightarrow \text{O}^{16}_{8} + \text{Mg}^{24}_{12} \quad (4)
\]

\[
\text{Ca} (-1.6 \%) = \text{O} (+0.6 \%) + \text{Mg} (+1.0 \%)
\]
SECOND GENERATION REACTIONS

\[ \text{Fe}^{56} \rightarrow 3\text{O}^{16} + \text{He}^2 + 4 \text{neutrons} \quad (2) \]

\[ \text{Fe} (-15.1 \%) = \text{O} (+12.9 \%) + \text{He} (+1.1 \%) + \text{neutrons} (+1.1) \]

\[ \text{Ca}^{40} \rightarrow 2\text{O}^{16} + 4\text{H}^1 + 4 \text{neutrons} \quad (3) \]

\[ \text{Ca} (-5.9 \%) = \text{O} (+4.7 \%) + \text{H} (+0.6 \%) + \text{neutrons} (+0.6 \%) \]

\[ \text{Ca}^{40} \rightarrow \text{O}^{16} + \text{Mg}^{24} \]

\[ \text{Ca} (-1.6 \%) = \text{O} (+0.6 \%) + \text{Mg} (+1.0 \%) \]

The calculated O increase of 18.2% is very close to the experimental value of 18.5%.
Considering the experimental residual 0.2% of Ca, and the previously calculated residual 3.3% of Ca, the following two reactions provide a complete matching:
Considering the experimental residual 0.2% of Ca, and the previously calculated residual 3.3% of Ca, the following two reactions provide a complete matching:

\[ \text{Ca}^{40}_{20} \rightarrow \text{K}^{39}_{19} + \text{H}^1_1 \]  

(5)

\[ \text{Ca} (-1.5 \%) = \text{K} (+1.5 \%) \]
Considering the experimental residual 0.2% of Ca, and the previously calculated residual 3.3% of Ca, the following two reactions provide a complete matching:

\[
\text{Ca}^{40}_{20} \rightarrow \text{K}^{39}_{19} + \text{H}^1_1 \quad (5)
\]

\[\text{Ca} (-1.5 \%) = \text{K} (+1.5 \%)
\]

\[
\text{Ca}^{40}_{20} \rightarrow \text{Si}^{28}_{14} + \text{C}^{12}_{6} \quad (6)
\]

\[\text{Ca} (-1.6 \%) = \text{Si} (+1.1 \%) + \text{C} (+0.5 \%)
\]
NICKEL ELECTRODE
Nickel (−23.1%)
Oxygen (+19.5%)
Element concentrations before and after the Electrolysis

<table>
<thead>
<tr>
<th>Mean Values</th>
<th>Ni</th>
<th>O</th>
<th>Si</th>
<th>Fe</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 0 hours (%)</td>
<td>91.6</td>
<td>2.0</td>
<td>0.3</td>
<td>2.4</td>
<td>0.0</td>
</tr>
<tr>
<td>After 20 hours (%)</td>
<td>68.5</td>
<td>21.5</td>
<td>1.1</td>
<td>0.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

\[ \text{Ni}^{59}_{28} \rightarrow 3\text{O}^{16}_8 + 2\text{He}^4_2 + 3 \text{ neutrons} \quad (7) \]

\[ \Rightarrow \text{Ni} \ (-22.1\%) = \text{O} \ (+18.0\%) + \text{He} \ (+3.0\%) + \text{neutrons} \ (+1.1\%) \]

The calculated O increase of 18.0% is not far from the experimental value of 19.5%.
\[
\text{Ni}^{59}_{28} \rightarrow 2\text{Si}^{28}_{14} + 3 \text{ neutrons}
\]
\( \text{Ni}^{59} \rightarrow 2\text{Si}^{28} + 3 \text{ neutrons} \) \hspace{1cm} (8)

\( \text{Ni} (-1.0\%) = \text{Si} (+0.9\%) + \text{neutrons} (+0.1) \)

\( \text{Fe}^{56} \rightarrow 2\text{Al}^{27} + 2 \text{ neutrons} \) \hspace{1cm} (9)

\( \text{Fe} (-2.0\%) = \text{Al} (+1.9\%) + \text{neutrons} (+0.1) \)
Compositional Analysis of the Electrodes

PALLADIUM ELECTRODE AFTER THE TEST

Macro-cracking after 20 hours

100µm
WAVELENGTH vs FREQUENCY

Earthquakes
Humans
Insects
Bacteria
Proteins

Metre

$10^3$ $10^0$ $10^{-3}$ $10^{-6}$ $10^{-9}$

Hertz

$10^0$ $10^3$ $10^6$ $10^9$ $10^{12}$

Earthquakes
Humans
Insects
Bacteria
Proteins
Wavelength vs Frequency

\[ f = \frac{v}{\lambda} \]

Nano-scale vs TeraHertz

\[ 10^{12} \text{ Hz} = \frac{10^3 \text{ ms}^{-1}}{10^{-9} \text{ m}} \]
Frequency vs Energy

\[ E = \hbar f \]

TeraHertz vs Vibrational Energy of the Atomic Lattice

\[ 0.025 \text{ eV} = 6.58 \times 10^{-16} \text{ eV} \times 3.8 \times 10^{13} \text{ Hz} \]
(1) The primary phenomenon appears to be a symmetric fission of the atom of nickel into two silicon atoms, or two atoms of magnesium. In the latter case, additional fragments were found to be constituted by alpha particles.

(2) In a second investigation, where a palladium electrode was used, the primary process appears to be the non-symmetric fission of palladium into iron and calcium, whereas the secondary processes appear to be the further fissions of both such products into oxygen and alpha particles.