Rossi's reactors--reality or fiction?

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Abstract:

A tabletop prototype of a new kind of nuclear reactor was demonstrated recently at the University of Bologna. This note addresses conceptual difficulties associated with the reported features of the device.

Introduction

An interesting website, describing an ongoing research project, has been created by an Italian engineer Andrea Rossi (1). He is the inventor of a tabletop device in which nickel is converted into copper, generating nuclear energy. The device was recently demonstrated at the University of Bologna. The most obvious questions, raised by the reported features of the reactor are:

a) How can relatively cold hydrogen, flowing through powdered nickel, generate nuclear reactions?

b) Is the reported accumulation of copper consistent with the well known half-lives of radioactive copper byproducts?

c) Is the measurable isotopic composition of nickel, in spent fuel, consistent with the amount of released energy?

d) The spent fuel was found to be non-radioactive; the radiation level, outside the operating 12 kW reactor, is comparable to that due to cosmic rays. Spent fuel, removed from the reactor, one hour after the shutdown, was found to be not radioactive. (1) How can this be explained?

Results from earlier experiments (2008 and 2009) are described in (2). In one case the device was used to heat a "small factory" (probably two or three rooms) for one year. What follows is based on recent results.

Reported results from recent experiments

A recent public demonstration of the device--January 14, 2011, at the University of Bologna--is described in (3,4,5). Another recent demonstration--February 10-11, 2011--is described in (6,7). In both cases the apparatus consisted of a cylinder containing nickel. Pure hydrogen was forced to flow through the hot nickel powder. The amount of powder was 100 grams (8), or slightly more than one cubic inch, depending on the level of compression. Reactions between nickel and hydrogen turned out to be extremely exothermic, generating thermal energy at the rate of about 12.4 kW. This was 31 times higher than the rate at which electric energy was supplied, to operate the equipment (4).

In the February experiment the amount of thermal energy was determined from the flow rate of cooling water, and the difference between its input and output temperature. In the January experiment the water flow rate was slower; the entering water was a liquid, the escaping water was a vapor. The amount of thermal energy released was determined from the amount of liquid water (initially at 15° C) transformed into 101°C vapor. Rossi claims that most heat is produced from nuclear reactions:

$$p+Ni \rightarrow Cu$$

where p is nothing but ionized hydrogen. This is very surprising because the temperature of hydrogen was much lower than 1000° C. Addressing this issue in (9) Rossi reported that about 30% of nickel was turned into copper, after six months of uninterrupted operation.

Comment 1

Many physicists have studied fusion of protons with nickel nuclei. But their protons had much higher energies, such as 14.3 MeV (10). Rossi's protons, by contrast, had very low energies, close to 0.04 eV. The probability of nuclear fusion, expressed in terms of measurable cross sections, is known to decrease rapidly when the energy is lowered. How can 0.04 eV protons fuse with nickel, whose atomic number is 28? Rossi is convinced that this is due a catalyst added to the powdered nickel. The nature of the catalyst has not been disclosed. This prevents attempts to replicate the experiments, or to discuss the topic theoretically. Secrecy might make sense in some business situations, but it is not consistent with scientific methodology.

Comment 2

How can 30% of nickel in Rossi's reactor be transmuted into copper? This seems to be impossible, even if the coulomb barrier is somehow reduced to zero by his catalyst. To justify this let us focus on the ^{58}Ni and ^{60}Ni isotopes--they constitute 94.1% of the nickel loaded initially into the device. The reactions, by which copper is produced, from these isotopes, would be:

$$p + {}^{58}Ni \rightarrow {}^{59}Cu \quad \text{(half-life is 3.2 s)} \qquad \text{(A)}$$

and

$$p + {}^{60}Ni \rightarrow {}^{61}Cu \quad \text{(half life is 3.3 hrs)} \qquad \text{(B)}$$

The reported amount of accumulated copper--30% of the initial nickel being turned into copper, after six months of operation--would indeed be possible, via reactions (A) and (B), if the produced copper isotopes were stable, or had half-lives much longer than six months. But this is not the case, as shown above. The produced copper isotopes, ^{59}Cu and ^{61}Cu, rapidly decay into ^{59}Ni and ^{61}Ni. Each reaction, in other words, leads to accumulation of these isotopes of nickel, not to accumulation of copper, as reported by Rossi. The growth in the amount of copper practically stops after two half-lives.

Note that ^{63}Cu and ^{65}Cu, if produced from fusion of protons with ^{62}Ni and ^{64}N, would be stable. But natural abundance of these isotopes of nickel, 3.7% and 1.8%, respectively, is too low to be consistent with the claimed accumulation of 30% of copper.

Comment 3

How much of the original ^{58}Ni should be destroyed, after six months of continuous operation, in order to generate thermal energy at the rate of 12 kW? Let us again assume that coulomb barriers are somehow reduced to zero by Rossi's secret catalyst. The ^{58}Ni is 68 % of the total. On that basis one can assume that 68% of 12 kW is due to the radioactive decay of ^{59}Cu, and its radioactive daughter, ^{59}Ni. Thus P1'=0.68*12=8.16 kW. This is the thermal power. The nuclear power P1 must be larger, because neutrinos and some gamma rays do escape from the vessel. As a rough estimate, assume that the nuclear power is

$$P1 = 16 \text{ kW} = 16{,}000 \text{ J/s} = 10^{17} \text{ MeV/s}$$

The excited ^{59}Cu, from the reaction (A), releases 3.8 MeV of energy, as one can verify using a table of known atomic masses. In the same way one can verify that the energy released from its radioactive daughter, ^{59}Ni, is 4.8 MeV. In other words, each transformation of ^{58}Ni into ^{60}N releases 3.8 + 4.8=8.6 MeV of nuclear energy.

The number of reactions (A) should thus be equal to $10^{17}/8.6 = 1.16*10^{16}$ per second. Multiplying this result by the number of seconds in six months ($1.55*10^{7}$) one finds that the total number of destroyed ^{58}Ni nuclei is $1.80*10^{23}$, or 17.4 grams. A similar estimate can be made for other initially present nickel isotopes. The overall conclusion is that the isotopic composition of nickel, after six months of operation, at the 12 kW level, would change drastically, if it were responsible for the heat produced in the reactor invented by Rossi. The isotopic composition of the unused nickel is well known. How does it compare to the isotopic composition of nickel in spent fuel?

Comment 4

The level of radioactivity, next to the reactor generating heat at the rate of 12 kW, was reported as not much higher than the natural background (5). Is this consistent with reaction (A) being responsible for most of the heat? The answer is negative. How can this be justified? In the steady state the rate at which radioactive atoms, in this case ^{59}Cu, are decaying is the same as the rate at which they are produced. That rate, as shown in Comment 3, is $1.16*10^{16}$ atoms per second. In other words, the expected activity is

$$1.16*10^{16} / 3.7*10^{10} = 313{,}000 \text{ Curies}$$

The emitted radiation would include gamma rays of 1.3 MeV, able to escape. The level of radiation, next to the reactor, would depend on the wall thickness. It would certainly exceed the background by many orders of magnitude. Absence of excessive gamma radiation might be an indication that the reactions producing heat were different from the p+Ni fusion.

This tentative conclusion is supported by another experimental fact. Spent fuel, removed from the reactor, one hour after the ending of a prolonged steady-state operation, was not at all radioactive, according to Rossi (1). Absence of radiation due to ^{59}Cu, one hour the reactor's shutdown, can be due to the short half-life of that isotope (1.3 min). But ^{61}Cu, produced via the reaction B, has the half life of 3.3 hrs; it would still be highly radioactive, one hour after the shutdown. The non-radioactive nature of spent fuel is not consistent with the idea that excess heat is produced via p+Ni fusion.

Addendum

The industrial 1000 kW plant, a set of fifty 20 kW reactors, now under construction in Athens, is expected to become operational in October 2011, according to Rossi. The cost of electricity from such plants, if widely used, is expected to be ten times lower than from our coal plants. Another desirable feature of the claimed reactor is that it “doesn’t produce radioactive waste (1).” What can be more desirable than higher safety and lower cost? Did Rossi really invent a new kind of nuclear reactor? Logical speculations, such as in the above comments, are not sufficient to answer this question, either positively or negatively. Only independently performed experiments can do this.

References:

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