Experimental evidence of emission of neutrons from cold hydrogen plasma[2)]

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We have tried to see experimentally whether there is some interaction between electric charges, other than the Coulombic one, and whether it may produce some kind of bound states between a proton and an electron, electrically neutral but different from a hydrogen-atom state. This requires that the stronger, and quicker, Coulombic interaction may be avoided by means of a high-frequency ionizing e.m. field. This field succeeds in maintaining a "cold" plasma i.e., a considerable number of protons mixed and colliding with an equal number of free electrons, for a time much larger than 10^{-8} sec. This limit is suggested by the known average recombination time of the ionized hydrogen atom.

1. INTRODUCTION

We have tried to see experimentally whether there is some interaction between electric charges, other than the Coulombic one,[3)] and whether it may produce some kind of bound states between a proton and an electron, electrically neutral but different from a hydrogen-atom state. This requires that the stronger, and quicker, Coulombic interaction may be avoided by means of a high-frequency ionizing e.m. field. This field succeeds in maintaining a "cold" plasma, i.e., a considerable number of protons mixed and colliding with an equal number of free electrons, for a time much larger than 10^{-8} sec. This limit is suggested by the known average recombination time of the ionized hydrogen atom. The high frequency has been taken to be of the order 10^{10} $\sec^{-1}$, with amplitudes large enough for ionizing the low-pressure pure hydrogen contained in the resonant cavities of a klystron-like oscillator. The excitation of this klystron[1] is actually obtained by means of a bunched beam of hydrogen ions, but it is probable that this excitation could also be achieved by means of a strong external microwave source. The device that we used works with an anode–cathode (grounded) potential difference of about 500 V. The fact that twice in a period the free protons and the free electrons are accelerated in opposite directions by the electric field of the microwave produces a considerable number of collisions between these particles.

Figure 1 shows a block diagram of our experiment, and Fig. 2 shows a schematic section of one of the oscillators that we built.

The hydrogen has always been obtained by electrolysis (water+H_2SO_4), dried on silica and filtered through a vacuum-tight palladium tube (25 cm long, 0.5 cm diameter, 0.1 cm thick). The eventual deuterium entering the vacuum system is only that obtainable by such a process, and is evaluated to be not more than 1/10 of the natural deuterium abundance, i.e., 10^{-3} of the H_1^1 abundance.

The pressure of the gas, in the oscillator is about 1.0.0.1 Torr. The oscillator has brass walls 0.2 cm thick, and the cavities are of stainless steel, also 0.2 cm thick. The size of the whole oscillator is 15 cm, with 5 cm diameter. A cooling water flow is necessary, but the cavities containing the plasma are settled outside the cooling layer so that eventual articles outgoing from them do not cross through the water. An improvement has been a focusing magnetic lens provided by a coil embracing the anodic part, with 250 rounds (No. 18 copper wire, 0.25 A) increasing the fraction f of the discharge current entering into the cavities. The cathode is a pile of disks shaping the cavities of the klystron. The expected effect is that, because of the microwave electric field, there is a very great number of collisions between free protons and free electrons, and when some protons and electrons form the above-mentioned neutral bound states, they may behave as neutrons and can cross through the walls of the oscillator. If it is the case that a number of samples of different elements settled outside the walls, we shall present a variation of their (β or γ) radioactivities, measured, before and after, as carefully as possible.

Great care has been taken to avoid contaminations, and in all measurements at least one twin sample has been carefully conserved unirradiated, as a control.

The results of several series of measurements made during about 3 years with a great number of samples have been positive without exception, although in some cases the induced activity was rather low, though always beyond statistical fluctuations. The kind of decay of the activated samples suggests that there is a small flux of neutrons arising from the cold plasma. This means that the expected non-Coulombic interaction implies the emission of a neutrino. This flux has been prevalently, measured by the activation of samples of several elements mostly obtained from the Institute of Atomic Energy of Sao Paulo, since the large noise due to the microwave field of the klystron makes the signal from BF_3 detectors uncertain, also with careful electric shielding. The somewhat erratic and low-level flux of neutrons limits severely the use of other techniques than those which integrate on a rather long time the flux into an observable activity.

Low induced activities have been observed with Ag, In, Au, Dy (metal and oxide), Sb_2O_3, Sb metal, Nd (2%) +Pr, Tl (metal and sulphate) (oxide). The resulting activities have been measured by means of a Philips anticoincidence system with a steady low background of 0.9 ± 0.1 cpm. This background has been systematically controlled in order to verify its Poisson-like distribution, as a proof of

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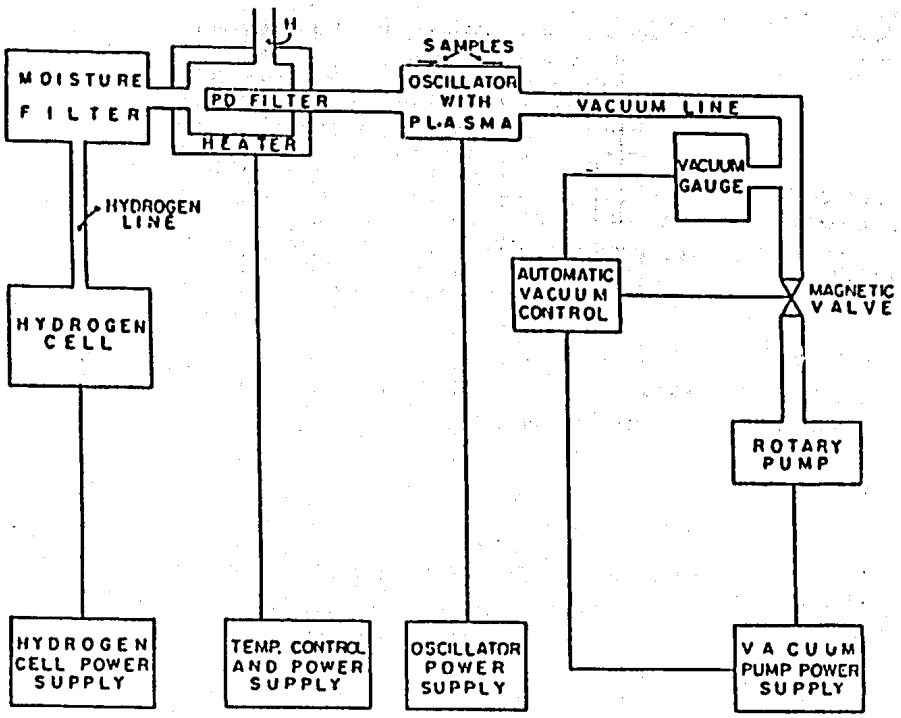

FIG. 1. A block diagram of the experiment.

no trouble in the counting system. For very low levels of induced activity (as for An, In, etc.) the measurement has been made by an average in a time as long as possible (several hours), and when possible (as for Dy, Sh, Pr +Nd, etc.) the half-lives have been checked with the least-squares method.

Here are examples of activation curves for some samples. Figure 3 shows the increasing beta activity of a 20 g sample of metallic Sb (Merck). Its starting background before any irradiation was 60 counts per hour, and its beginning activity of about 180 cph in Fig. 3 is due to the preceding activation. The general feature of Fig. 3 is linear; therefore it may be prevalently related to Sb^{123} $(n,\gamma)Sb^{124}$ with a period of 60 days. Figure 4 shows the decay of another sample of Sb (oxide). Figure 5 gives the special case of Th described below. Figure 6 gives the activity of a Dy sample during a 100-day exposure, interrupted by various observations of the decay, showing somewhat erratic working of the activating source. Figure 7 shows the decay of this Dy sample, starting where Fig. 6 ends. All these cases, as well as several others, show that some neutron flux actually exists.

This evidence is stronger from irradiated samples of Th and U. For U we used cylinders of high-density (10 g/cm^3) centerized U_3O_8 (to be used as reactor fuel with natural uranium) weighing 9 g. Its beginning gamma activity 142 700±400 cpm becomes 144 860±400 after some 3 hours of irradiation, and thereafter may be observed to decay to the starting value with a half-life of about 30^m, probably due to short-lived fission products, as suggested by the secondary maximum "delayed" by about 5 min (Fig. 8, obtained as an average of 10 observed decays). Indeed, there are almost two observable periods, namely, about 2^m and 30^m [see Ref. 2, where the authors fit, for example, the fission products Se^{84} (2^m), Br^{84} (32^m), Kr^{84}, which are 1% for U^{235} with thermal neutrons and 0.85% for U^{238} with fast neutrons]. Measurements on U may be daily repeated, thus giving good statistics. Instead, Fig. 5 shows the increase in gamma activity of a sample of 3.2 g of Th^{232}, discussed in more detail below. The decay curve is fairly clear. The data on neutron sections and resonance peaks are taken from Ref. 3. More detailed data and diagrams for these activations are given in No. 25 of Comunicacoes do Centro de Energia Nuclear; quoted in Ref. 2 (in English). The same results have been repeatedly observed with other series of samples of Th. Thus, from a qualitative standpoint, all the samples, after a conveniently long exposure near the external wall of the klystron (for hours, several days, or months), show an activity clearly many times above many reasonable fluctuation of the background, as well as evident decays with short periods, whose origin cannot be other than a recent activation. All this strongly suggests the existence of a small flux of neutrons outgoing from the device.

2. TENTATIVE EVALUATION OF THE FLUX

(i) The as yet unknown energy spectrum of these neutrons makes the values of the (n,γ) cross sections uncertain as well, for the majority of sample elements that we used. For them no definite flux calculation is allowed.

(ii) The activity increase of about 2000±500 cpm of the uranium quoted above, supposed to be at saturation, gives a flux

$$\phi = 2000/(\eta\Omega\Sigma_a \times 60)\, n/\text{sec},$$

where $\eta = 10^{-3}$ is the efficiency of the phototube; $\Sigma_a = 1$ cm^{-1} is the macroscopic cross section, approximately constant for a large energy range, and $x = 1$ cm is the sample thickness; $\Omega = 1/25$ is the solid angle. Hence $\phi = 10^6\, n/\text{sec}$.

(iii) The activation of Th^{232} samples, sealed in plastic tubes and in secular equilibrium with its family, has been

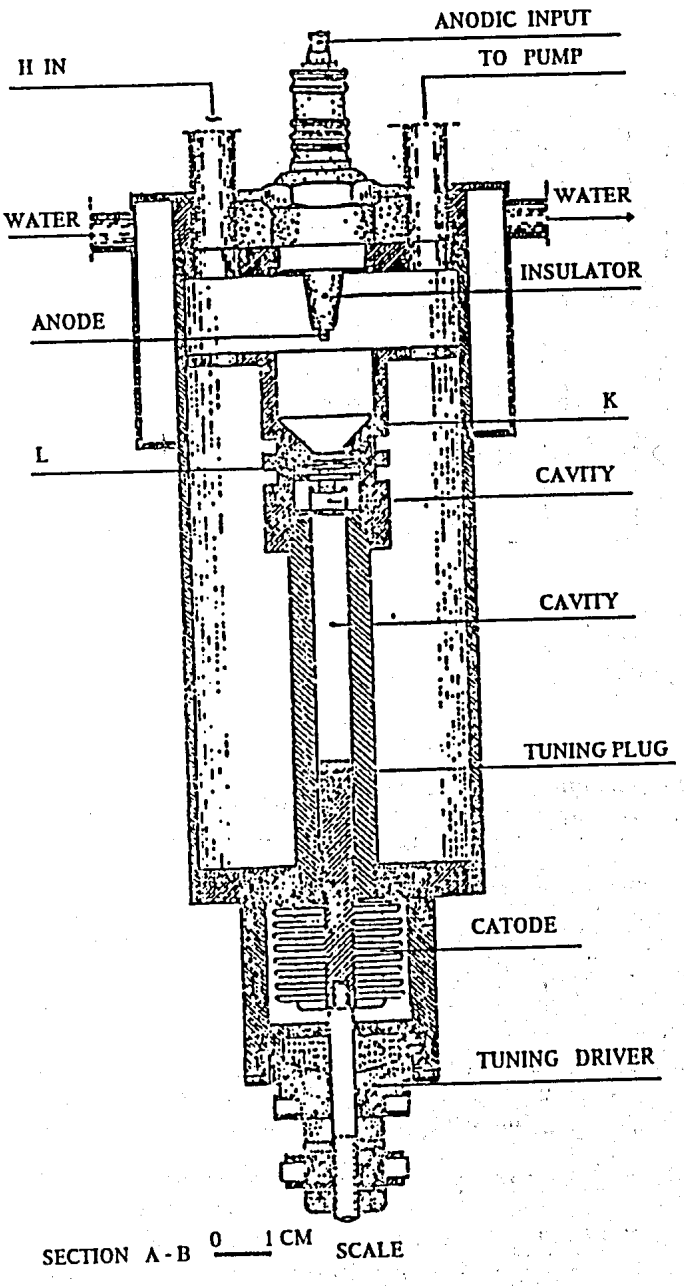

FIG. 2. A schematic section of the oscillator.

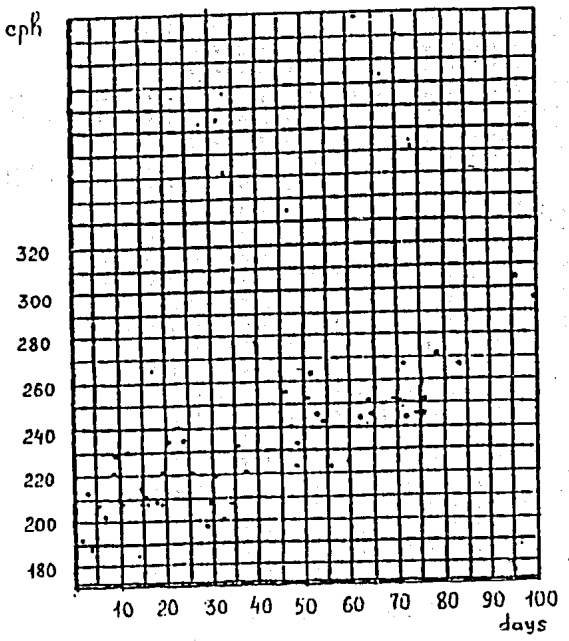

FIG. 3. The increasing beta activity of a sample of metallic Sb (20 g)—activation curve—December 1970–April 1971.

repeatedly observed (Fig. 5). One sample is conserved as a control, and another has been irradiated for 13 days, showing an increasing gamma activity, measured by a well crystal NaI(Tl) phototube (Tracerlab), $1''\times1''$. From the initial gamma activity 27 750±150 cpm of both samples, the irradiated one reached 43 580±210 cpm, with a difference 16 030±210 cpm. The activated sample was retired and thereafter decayed toward a level 39 300±200 cpm in 34 days, staying there for about 3 months, before it was irradiated again, showing similar results. The final difference in activity, 11 500±200 cpm. is 41% of the initial activity. The analysis of the decay suggests a principal contribution of Pa^{233} ($T_{1/2}=27$ days), mixed with small quantities of nuclides with $T_{1/2}=27$ days. Using an oversimplified method, the 41% increase of activity can be thought of as due principally to the produced U^{233} ($T_{1/2}=1.62\times10^5$ yr) mixed with a small percentage g (e.g., $g=10^{-3}$) of elements with shorter $T_{1/2}$, of the order of several years, because of the constancy of the measured final activity. Thus, the number N_{233} of U^{233} nuclei is

$$N_{233}=0.41\times N_{Th^{233}}\frac{\lambda_{Th^{232}}}{\lambda_{U^{233}}}\frac{1}{R}=\frac{4}{R}\cdot10^{16}\text{ nuclei},$$

where R represents a mixing factor: $R=(1-g)+g(1.52\cdot10^5/T')$. If T' is short enough (e.g., 10 yr), with, e.g., $g=10^{-3}$, we have $R=10^{-4}$. Thus, $N_{233}=10^{12}$, accumulated in 13 days, whence 10 nuclei of Th^{233} are

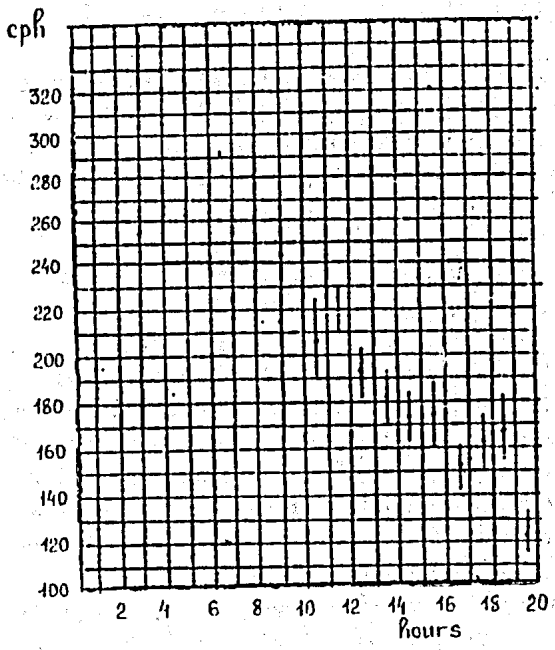

FIG. 4. Decay of a sample of Sb (oxide) after activation.

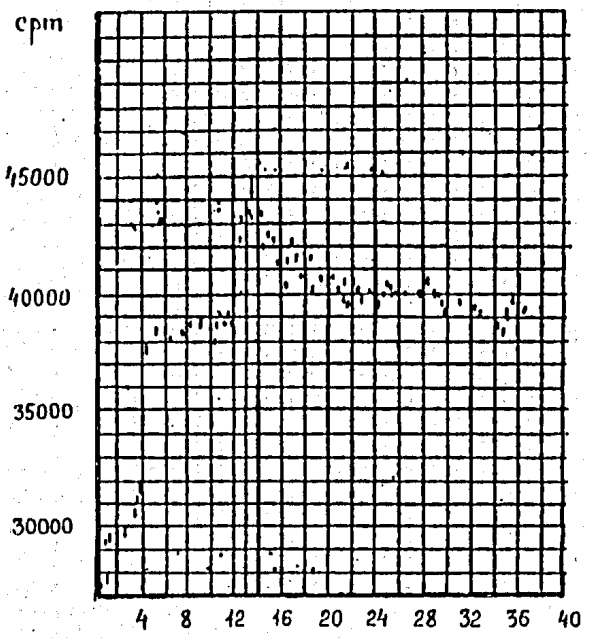

FIG. 5. Activation and decay of a sample of Th (oxide) (4.37 g).

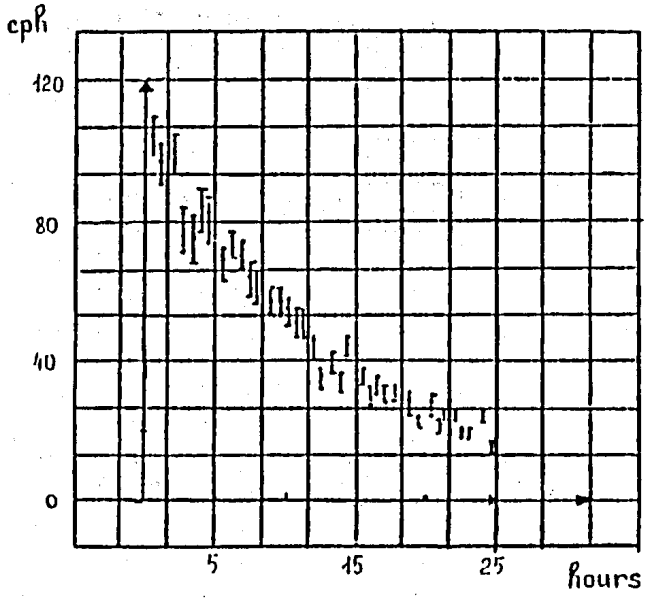

FIG. 7. Decay of a sample of Dy.

produced per sec. Therefore $\approx 10^6$ *n*/sec may be counted, as a probable order of magnitude of the neutron flux through this sample, consistent with that calculated with the uranium.

3. DISCUSSION

It seems evident that no properly called fusion is responsible for the production of these neutrons with a plasma nearly at room temperature, in our case.

The possibility that the observed neutrons arise from *d–d* reactions between deuterons contained in the cold plasma and/or deuterons somehow adsorbed in the walls seems the unique alternative interpretation of the reported evidence, other than a direct non-Coulombic interaction between proton and electron.

Now, the hydrogen used in the experiment is produced by electrolysis of $H_2O+H_2SO_4$, with a current of ≈ 1 A. The water is slightly enriched in D_2O because of long periods of electrolyis A preliminary measurement with a mass spectrometer (Varian G D 150) has shown that the D_2O content is as large as about 4 times its normal value 1/136. It is known that the electrolytic hydrogen contains about 1/20 of the deuterium abundance in electrolyzed water, whence in our case the deuterium abundance in the gas is about $4/(136\times 20)-1/630$ relative to H_1^1. Therefore the D_1^2 percentage in the input flow of hydrogen into the klystron is 1/1000, and the number of D_1^2 atoms in 5 cm^3 at 10^{-1} Torr pressure is about 10^{13} versus about 10^{16} atoms H_1^1 therein. Possible *d–d* reactions could actually exist in the klystron if (I) some noticeable amount of deuterium is

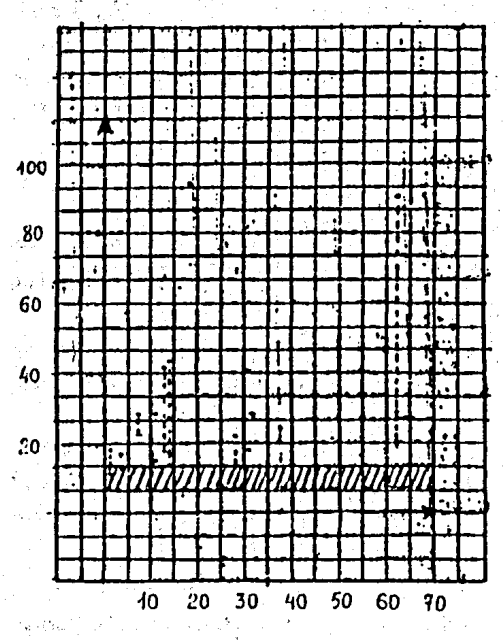

FIG. 6. Activation of a sample of Dy.

TABLE I.

Element	Net mass (g)	Date	Maxnet activity ($c/10^m$)
Dy (oxide)	2.580	13/02/70	83
		06/08/70	107
Nb (oxide)	2.128	26/02/70	61
		04/08/70	47
Pr (oxide)	5.361	26/01/70	69
		27/07/70	118
Sb (oxide)	2.688	18/02/70	51
		24/07/70	97
In (metallic)	0.135	21/01/70	54
Ag (metallic)	2.130	12/02/70	51
		16/06/70	17
Au (metallic)	0.960	23/02/70	10
		10/07/70	27
Tl (metallic)	10.260	14/02/70	41

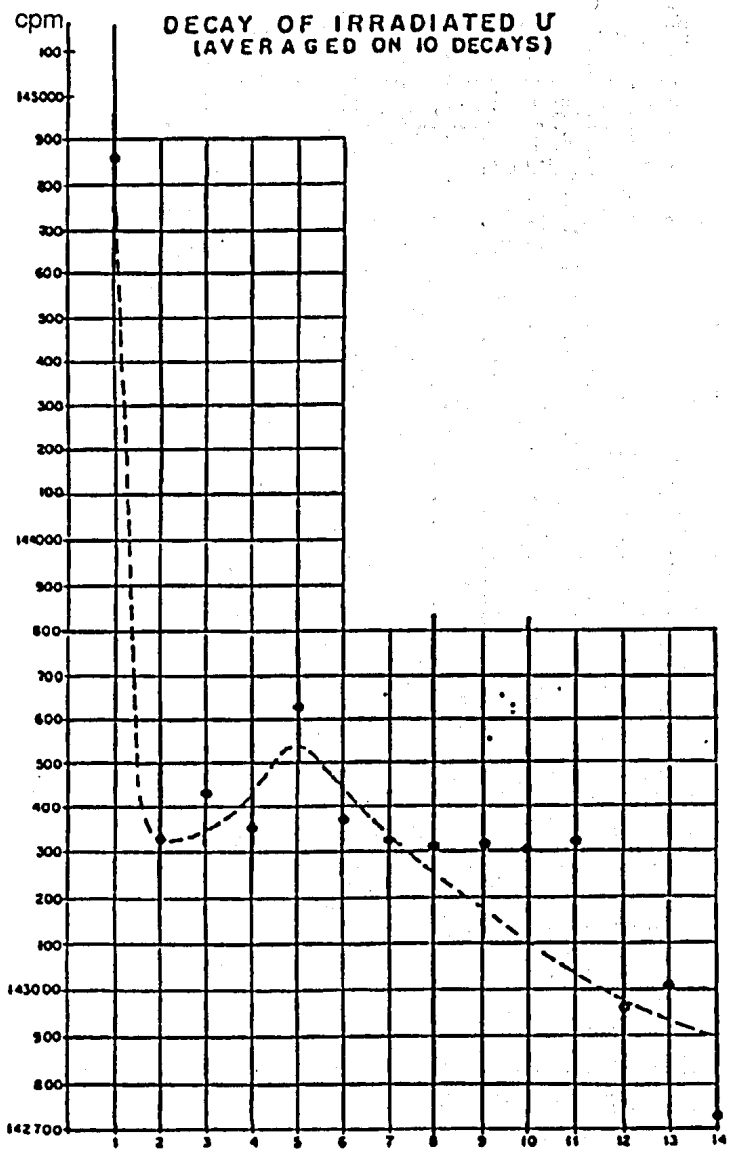

FIG. 8. Decay of irradiated samples of U.

adsorbed by the inner wall, which is of stainless steel; (II) a beam of D_1^2 ions with sufficient intensity and energy falls onto these D-imbedded walls, or on the D_1^2 nuclei in the gas (see the references in Ref. 2). If this is the case, the energy of the produced neutrons is of the order of 2 MeV. But the requirement (I) has a very slim probability of being realized in the stainless steel walls, without proper treatment and with a percentage of D_1^2 as low as 10^{-3}, as seen. As far as the requirement (II) is concerned, it is difficult to find how the D_1^2 ions may acquire a kinetic energy sufficiently large for getting a nonvanishing value for the *d–d* cross section. Indeed, a threshold of about 5 keV is probably required for this purpose (see Ref. 4) while the klystron works at a voltage of 500 V to ground. On the other hand, the peak-to-peak voltage of the microwave e.m. field could reach 5000 V only if the e.m. energy involved were much larger than that due to the probably small power produced in the klystron. Thus, it is very improbable that (*d*,*d*) reactions give an important contribution to the observed production of neutrons. Indeed, taking the fraction $f<1$ of the total current (200 mA) actually entering into the oscillating cavity, the fraction of it due to deuterons is about 1/10 of the input abundance 1/1000, because of the mass ratio $1/\sqrt{2}$ with light hydrogen, and of the presence of molecular ions HH+DD+. Thus, the maximum deuteron current is $0.2\times1.3\times10^{19}\times10^{-4}\ f=2.6\times10^{14}\ f\ \text{sec}^{-1}$. The target (walls+gas at 10^{-1} Torr) has about $10^{19}\times10^{-4}=10^{15}$ deuterons/cm^2. The *d–d* cross section for 500 eV is about 1 mb$=10^{-27}$ cm^2. Therefore the *d–d* contribution of the neutron flux may be expected to be

$$N_{dd}=2.6\times10^{14}\times10^{15},\quad 10^{-27}f=260f\ \ n/\text{sec}.$$

As a matter of fact, f can be taken to be the ratio of the inlet hole area of the klystron versus the whole discharge cross-section area.

In our device this ratio is 1/36. With this value one has $N_{dd}=7n$/sec. This is several orders of magnitude less than the observed flux.

Hence we may conclude that this experiment seems to confirm the possibility of observing directly the assumed non-Coulombic interaction between protons and electrons.

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[2)]Presented by R. M. Santilli, Institute for Basic Research, Palm Harbor, FL 34682-1577, U.S.A.

[3)]This weak interaction may be the same as that observed in nuclear phenomena.

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[2]O. R. Frisch, *Nuclear Handbook* (London, 1958), p. 11.

[3]D. J. Hughes and J. A. Harvey, *Neutron Cross Sections* (U.S.A.F.C., 1955).

[4]E. A. Durrill, Nucleonics **18**, 11865 (1960); E. Segreu, *Experimental Nuclear Physics* (Wiley, 1953), Vol. 2, p. 380; D. Reifenschweiler, Nucleonics **18**, 70 (1960).