The MR(Jr) cell was a smaller version of the Milton Roy cell with 6 Pd-Ag alloy tubes. This cell has earlier been used for routine $H_2$ generation for several years at the Chemistry Division. Cell #11 was a very novel cell wherein the electrolyte was KOD in the form of a paste applied on a multiwire grid electrode system made of alternate wires (0.5 mm dia) of Pd and Pt. Although this gave excess tritium of only $2 \times 10^{10}$ atoms (lowest in the Table) it must be noted that the total inventory of electrolyte in this microcell was hardly 1.5 ml. In Cell #8 (PDR-I) an RF voltage was superposed on the applied DC voltage with a view to ascertain whether this would help improve the tritium production. As seen from the results there is no evidence of any improvement.

The Cells # 5, 6, & 7 used the same hollow Pd cylinder cathode deployed in Cell # 6 of Table I (Expt. PDC-I). As in the case of PDC-I current pulsing was resorted to in these three PDC series of experiments also. On completion of PDC-I the hollow Pd cathode was degassed at 300ºC in a vacuum furnace for over 2 hrs. Subsequent electrolysis in 0.1 M LiOD (Expt. PDC-II) terminated in an explosion after a charge of 423 amp-hrs had been passed. Careful measurements of the tritium content indicated that over 2 MBq ($1.1 \times 10^{15}$ atoms) of excess tritium had been generated during this experiment, (see Table II). This corresponds to an increase in tritium inventory by a factor of more than 20,000 relative to the total tritium input to this experiment.

This same cathode generated tritium two more times after degassing and reuse. (PDC-III & PDC-IV). But as seen from Table II in each subsequent run the quantum of tritium generated decreased further. For example in PDC-III while excess tritium recovered was 2.96 kBq, in PDC-IV the excess tritium was only 629 Bq even after 123 amp-hrs of charging. Prior to commencement of PDC-IV the electrode had been heated to 850ºC for 4 hrs in vacuum, cooled and again heated to 800ºC in $D_2$ gas atmosphere at 1 cm pressure for 3 hrs followed by degassing again under vacuum for 3 hrs. This very elaborate pretreatment would have cleansed the Pd of any remnant tritium within its interior, confirming that the fresh amount 629 Bq obtained in PDC-IV must have been generated during this run of electrolysis only. But the more important implication of this result is that even vacuum heating-annealing does not appear to have restored the ability of the Pd cathode to support nuclear reactions.

## 6. REAL TIME NEUTRON DIFFRACTION STUDY OF DEUTERON LOADING IN A Pd CATHODE /11/

Cell #9 (CD-4 of Chemistry Division) was primarily designed for conducting an online neutron diffraction study of the phase change occurring during the deuteration of a Pd rod. It is comprised of a covered Pyrex glass beaker with an 8 mm dia × 16 mm long Pd cathode of which 11 mm protruded underneath the cell and was set up in front of one of the neutron beams at the Dhruva research reactor at Trombay. The portion of the Pd rod exposed to atmosphere was given a thin protective coating of tin to minimise escape of deuterium. A platinum cell above the cathode served as anode and the electrolyte was 0.1M $Li_2O$ in $D_2O$. A 0.18 mm thick Nafion membrane between the electrodes helped prevent direct recombination of deuterium and oxygen. Electrolysis was carried out at a steady current of 100 mA extending over a period of more than 8 weeks. Powder diffraction patterns were recorded periodically with the help of a 1 metre wide position sensitive neutron detector mounted so as to provide a 30° angular span. With this arrangement the real time development of the (111), (200) and (311) reflections could be studied.



## 4. SUMMARY OF ELECTROLYSIS EXPERIMENTS WITH NEUTRON AND TRITIUM GENERATION

Table I presents a summary of the successful electrolysis experiments conducted so far at Trombay wherein significant amounts of both neutron and tritium production has been observed. Also included (last column of Table I) for comparison and completeness are the results of an experiment /9/ conducted at the Indira Gandhi Centre for Atomic Research (IGCAR) in Kalpakkam, Tamil Nadu, a sister Institution of BARC. The main conclusions to emerge out of these results are discussed later.

## 5. OTHER TRITIUM PRODUCING CELLS / EXPERIMENTS

Besides the above electrolysis experiments wherein both tritium and neutron production has been observed, there have been an additional 11 cells / experiments wherein clear evidence for excess tritium generation has been obtained. The majority of these experiments were carried out in the various divisions belonging to the "Chemical Group" of BARC. Table II summarises these results. In most of these experiments neutron yield, if any, was not monitored due to non-availability of detectors with the groups concerned. In the few cases where neutron detectors were present the increase in count rates if any was not significant enough within the statistics of the background count rate variations. Some of the cells of Table II were of closed type wherein the electrolytic gases were recombined by means of a suitable catalyst.

deduced. It was summarised from the study that the stochiometry at saturation was $PdD_{0.55}$. The main conclusion of this experiment relevant to cold fusion is that no new phases develop in Pd even after 100 amp-hrs of electrolysis.

# PART B: $D_2$ GAS LOADING EXPERIMENTS

## 7.1 SEARCH FOR TRITIUM IN GAS LOADED Pd SAMPLES /5/

In these experiments $D_2$ gas was loaded into Pd samples after thoroughly degassing them and a search was made for the possible production of tritium in the samples. The tritium produced, if any, along with that in the initially loaded deuterium was extracted through isotopic exchange with distilled light water wherein the Pd sample itself served as a catalyst. From the activity measured in the water the amount of tritium "produced" in the Pd was computed,

$D_2$ gas was generated by reducing $D_2O$ with Na in vacuum and stored under pressure in an SS dewar with liquid nitrogen cooling, in the presence of activated charcoal. The stock $D_2O$ used had a tritium content of 0.075 nCi/ml (2.8 Bq/ml), corresponding to a (T/D) isotopic ratio of $3 \times 10^{-14}$. Pd samples either in the form of Pd black powder or Johnson & Matthey Pd-Ag foils were taken in an SS reaction vessel connected to a vacuum system ($10^{-5}$ mm) through a buffer tank of 1 litre volume equipped with a pressure gauge. After degassing and cooling under vacuum, $D_2$ gas at 1 atm pressure was let into the buffer tank and the system sealed off for equilibration with the Pd contained in the reaction vessel for several hours or days at times. From the pressure drop observed the quantity of gas absorbed in the Pd could be deduced. The deuterated Pd samples were later immersed inside a measured quantity of distilled water for a few hours and the concentration of tritium in the water measured through standard liquid scintillation counting systems. The tritium content in the Pd was deduced therefrom knowing the gram moles of $D_2$ absorbed in Pd as well as the relevant equilibration constant (K).

Table III summarizes the results. The tritium activity measured in the distilled water was a small fraction of a nCi/ml (5 to 30 Bq/ml). The total quantity of tritium estimated to have been generated in the Pd foils is in the region of $10^{10}$ to $10^{11}$ atoms. It is observed that the (D/Pd) ratios attained following $D_2$ absorption are approximately similar in all the cases (0.20 to 0.63). The amount of tritium produced per gram of Pd sample varies widely, from ~1.2 to $20.8 \times 10^{10}$ atoms/g. As may be expected the higher value is consistent with the longer duration of equilibration time (240 hours) between D and Pd, but the large Pd foil (column #3) which was also equilibrated for 240 hours has given only $2.2 \times 10^{10}$ atoms of t/g of Pd. In all cases the finally attained (T/D) ratios which are in the range of $.3 \times 10^{-11}$ to $8.3 \times 10^{-11}$ are two to three orders of magnitude higher than that of the initial gas value namely ~ $3 \times 10^{-14}$. Thus fresh tritium amounting to about $10^{10}$ or $10^{11}$ atoms appears to have been created in the Pd, presumably due to "cold fusion" reactions. It is not clear whether the tritium was produced during the absorption process or during the subsequent "curing" or equilibration phase.



## 3.4 Pd RING AND Pd COIL CELLS WITH NAFION MEMBRANE (ApCD)

In both these experiments the cathodes were thoroughly degassed and vacuum annealed ($<10^{-3}$ mm Hg, 1070 K, ~10 hours) prior to electrolysis. The anode was a cylindrical Pt mesh covering the cathode on all sides. In the first experiment the Pd ring cathode (2.5 cm dia, 1 cm height and 0.1 cm thickness) was charged from both the sides /5/. In the second experiment a thin Pd rod (1 mm dia × 14 cm length) formed into a coil was employed as cathode /8/. In both these experiments the anodes were loosely sandwiched between pairs of Nafion membranes so as to prevent the oxygen evolved at the anode to diffuse back to the cathode surface. The electrolyte (0.1M LiOD in $D_2O$ of 99.86% isotopic purity) was circulated through the quartz electrolytic cell to reduce the dissolved oxygen level further. A saturated calomel electrode dipping in the electrolyte was used to monitor the cathode potential. The cell was operated at relatively low current density of ~60 mA/$cm^2$.

Neutron detection was carried out by means of a well type counter containing 24 $He_3$ detectors embedded in an annular block of paraffin. The test cell was located at the centre of this well, giving a neutron detection efficiency of 8.6%. Data acquisition was carried out with the help of a personal computer having multi-scaling mode facility. The counting time per channel was set as 40s. It was ensured that the overall neutron detection system was immune to extraneous influences which could give false counts. The background reference counts were observed to be steady at ~1.6 cps for about 10 days before start of the experiments.

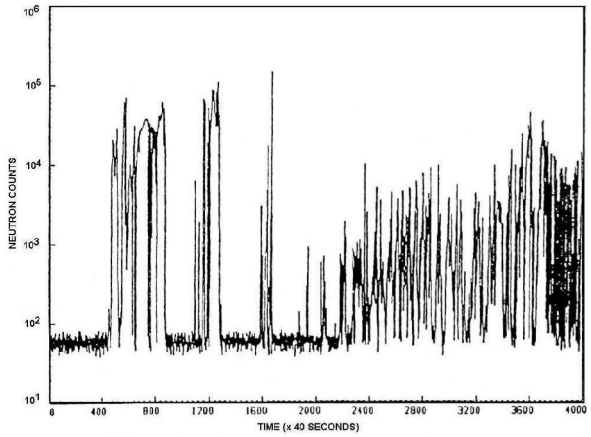


**Fig. 8. Neutron Bursts of Pd Ring Cathode Experiment of ApCD**

The ring cathode electrolysis experiment was run for 32 days commencing from 6th of July 1989. Between the 14th and 17th days from start of electrolysis copious emission of neutrons in the form of bursts was recorded. Otherwise the count rate remained close to background levels for the rest of the period. Fig. 8 depicts the neutron counts variation over the entire 44 hour (4000 × 40s) duration, while Fig. 9 gives an expanded view of a part of the same data. The log scale of the counts axis should be noted, indicating that the bursts were indeed intense, the peak neutron emission rate being ~1000 times background levels. The total neutron emission over the

system described in Sec 3.4 was used for the neutron yield measurements. The counting efficiency was determined to be 10%.

In these experiments first conducted in June 1989, Ti pieces were to begin with equilibrated with $D_2$ gas at 10 atm and 77 K for ~20 minutes. The temperature was then allowed to increase slowly to ambient level, with simultaneous evacuation resulting in desorption of $D_2$ gas from the Ti shavings. This resulted in large neutron bursts lasting between half an hour to ~2 hours each as shown in Figs. 12a to 12d. Prior to the experiments of Figs 12c & 12d, the $D_2$ gas pressure and temperature were simultaneously cycled. While the first three measurements were carried out with the same charge of Ti, the last one was done with a fresh charge which could be the reason for the slightly different characteristics of Fig. 12d. The integrated neutron yield in these experiments varied in the range of $10^5$ to $10^7$ neutrons.

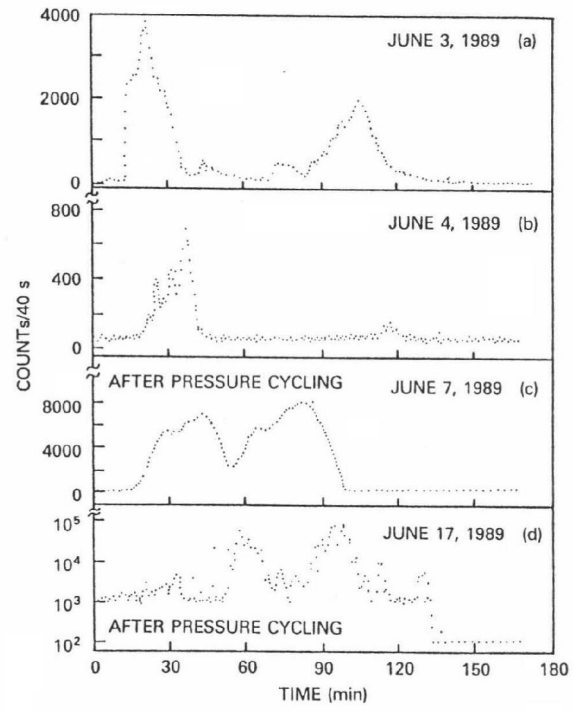


**Fig. 12. Neutron Counts Variation During Frascati Type Experiment with Ti Shavings**

The authors of these measurements have reportedly been unsuccessful in their attempts to measure neutrons again in repeated attempts to reproduce the earlier results /13/. However they have detected the presence of tritium in some of the newly loaded Ti shavings through the technique of autoradiography. For this they employed a high speed Polaroid camera. A 25 μm thick aluminium foil placed between the shavings and the photo sensitive film ensured that false



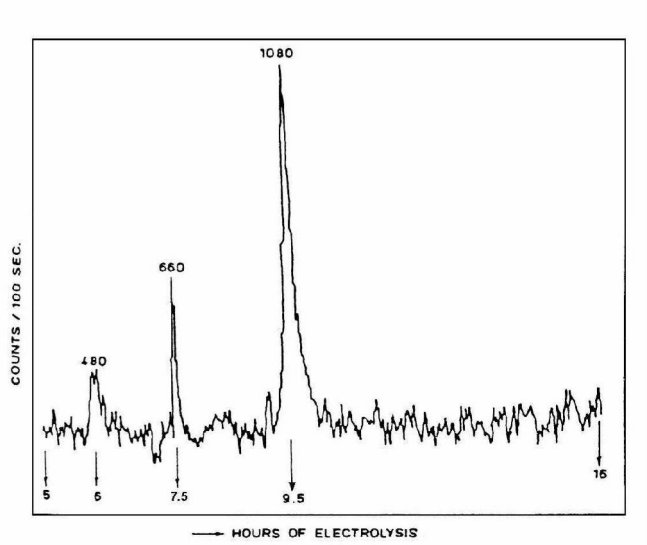


**Fig. 6. Neutron Yield PDC-I Cell: 1186 keV Capture gamma Counts**

## 3.2 Pd CUBE EXPERIMENT (ROMG) /5/

In this experiment the cathode was a 1 $cm^3$ of Pd and anode a Pt wire gauze formed into a cylinder surrounding the cube. The electrolyte was 0.1 M LiOD in $D_2O$. The electrolytic gases were recombined using a Pd catalyst; excess $D_2$ was converted into $D_2O$ using hot copper oxide. Although the main objective of these experiments was measurement of excess heat, in this paper only the neutron and tritium results are reported.

The neutron yield was monitored by means of a paraffin encased $BF_3$ counter mounted immediately underneath the table where the cell was located. A second $BF_3$ detector placed about a metre away monitored background neutrons. The cell electrolyte as well as the $D_2O$ collected in the various cold traps in the system were periodically sampled for tritium measurements. Electrolysis was carried out at a current of ~0.6 amps. After about 24 hrs when ~14.7 amp-hrs of charge had been passed, bursts of neutrons began to be observed. In all 17 neutron bursts lasting from 2 mins to 55 mins each were recorded. The neutron yield in the bursts varied from $5 \times 10^3$ (2 min burst) to $5 \times 10^5$ (8 min burst). Altogether a total of $1.4 \times 10^6$ neutrons was estimated to have been generated. Thereafter there were no more neutron bursts although the electrolysis continued for a further period of seven weeks (a total of 1365 amp-hrs).

A detailed accounting of tritium distributed in various constituents such as electrolyte, vapour condensate recovered from recombined gases, gases extracted from Pd electrode etc was carried out by this group. It was concluded that in all about 35 nCi or $6.7 \times 10^{11}$ atoms of excess tritium was produced in this experiment. This corresponds to a gross neutron-to-tritium yield ratio of $1.7 \times 10^{-6}$.

TABLE IV

TRITIUM CONTENT IN $D_2$ GAS LOADED Ti TARGETS

| | | | |
|---|---|---|---|
| Date of loading | 14 June 89 | 9 June 89 | 21 Mar 90 |
| Shape of sample | Disc | Cone | Cone |
| Sample mass (g) | .98 | .206 | .2 |
| $D_2$ absorbed (mg) | .42 | .07 | .29 |
| T activity from X-ray counts (bq) | 290 | 1300 | $5.5\times10^{6}$ |
| Date of counting | 16 June 89 | 16 June 89 | 28 Mar 90 |
| Tritium atoms | $1.5\times10^{11}$ | $6.5\times10^{11}$ | $3.0\times10^{11}$ |
| T/D ratio | $1.2\times10^{-9}$ | $3.2\times10^{-8}$ | $7.1\times10^{-5}$ |

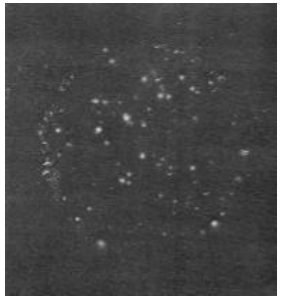

**Fig. 13. Autoradiograph of Deuterated Ti Disc**

Interestingly one of these disc targets which was kept in front of a paraffin encased $BF_3$ neutron detector and monitored over a weekend, suddenly emitted a large burst of neutrons on its own lasting over a time span of 85 mins. (See Fig. 2 of companion BARC paper /6/) The most intriguing feature of this experiment is that ever since the RF heating system became defective in September 89, these results could not be reproduced even once using a resistance furnace even though the power was higher and much greater quantities of $D_2$ gas could be absorbed. It was only in March 90 when a 1MHz furnace became available that a conical target once again indicated the presence of μCi amounts of tritium (See Table IV). The authors are therefore obliged to conclude that oscillatory electric and magnetic fields somehow play a crucial role in stimulating anomalous nuclear reactions on the surface of these machined Ti targets. In this context the recent Coherent Theory of Cold Fusion proposed by Hagelstein /14/ appears to give some theoretical insight as to possible mechanisms which could explain these observations.



bottom ensured coaxial alignment, as well as leak tightness. A vent at the top permitted free escape of electrolytic gases. A second cell of identical design was also fabricated for use as a control cell with $H_2O$.

5M NaOD in $D_2O$ was used as electrolyte. The current density was ~400 mA/cm$^2$. The main problem with this cell was the continuous deposition of a dull black coating of iron on the cathode which impaired operation. The electrolytic solution also developed a pale greenish yellow colour. The electrode surface had therefore to be cleaned frequently and fresh electrolyte charged, interrupting electrolysis. On the whole it was a messy operation.

The neutron yield during this experiment was monitored by the bank of 3 $He^3$ counters embedded in paraffin. The count rate was initially about 240 counts/10s, comparable to the count rates observed during an initial $H_2O$ electrolysis run. After about 3 hours of $D_2O$ electrolysis the count rate increased slowly to ~590 counts/10s. Since no big neutron bursts as in the Pd cathode cells were observed it was suspected that this gradual increase in counts could have been due to amplifier drifts, etc. On switching off the cell current it was noted that the count rate came down to ~385 counts/10s, but it did not quite reach the earlier background levels. When the cell was switched on again however the count rate attained levels of about ~590 counts/s once again. Thereafter operation of the cell was terminated and it was confirmed that the count rate decreased to the original background levels when the cell was removed from the vicinity of the neutron detector. Throughout this experiment the counts of the plastic scintillator channel monitoring the background did not show any significant variation. In all ~ $3 \times 10^7$ neutrons were generated during this experiment.

A sample of the electrolyte sent for analysis at the end of the experiment indicated tritium activity of ~48 nCi/ml (1.78 kBq/ml), a three order of magnitude increase over the initial stock solution value of ~0.05 nCi/ml (1.9 Bq/ml). The net excess tritium produced after correcting for tritium input through make up $D_2O$ addition etc, works out to ~7 μCi or ~$1.4 \times 10^{14}$ atoms of T. Admittedly this was not a very clean experiment, but even so one can obtain a very rough value for the neutron-to-tritium yield ratio as $2 \times 10^{-7}$ for this experiment.

## 2.5 Pd-Ti PARALLEL PLATE CELL

A simple parallel plate cell with Teflon button spacers was fabricated with Pd (0.5 mm thick) and Ti (1 mm thick) plates (40 × 50 mm$^2$) as electrodes. The inter-electrode gap was ~2 mm A thin platinum strip was spot welded at the top of the Pd to serve as current feed through, The parallel plate assembly was suspended inside a 300 ml glass bulb having a wide mouth at the top. A vent hole in the stopper permitted escape of electrolytic gases. An advantage of this cell was that either Pd or Ti could be selected as cathode with the other serving as anode.

Electrolysis was commenced on 15$^{th}$ March 1990 with Pd as cathode and 5M NaOD in $D_2O$ as electrolyte. Current density was adjusted to be ~200 mA/cm$^2$. Three neutron detectors were available for monitoring neutron output, two for viewing the cell and the third for serving as background monitor. Two consecutive neutron bursts occurred about 4 hours after commencement of electrolysis. The background counts were absolutely flat during this run (see Fig. 5). It was noted that the Pd cathode had buckled outwards and had become extremely hardened. The buckling can be explained on the basis of differential loading of $D_2$ across the thickness of the metal.

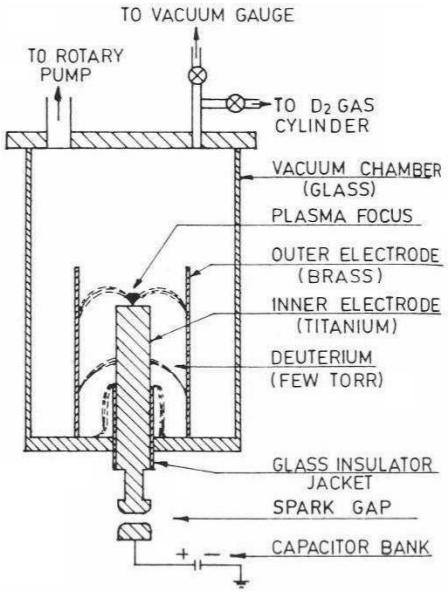


**Fig. 15. Schematic Diagram of a Plasma Focus Device With Central Ti Electrode**

During January 90 an experimental program was underway to study the influence of anode material on the characteristics of the plasma created and consequently on the neutron production mechanisms of a PF device. Brass, aluminium, stainless steel and titanium were investigated for neutron yield systematics under various deuterium filling pressures (1-10 mbar).

During the experiments with a Ti anode, about 80 charge/discharge shots were carried out. After each shot the chamber was flushed and filled with fresh $D_2$ gas. Some of these shots were performed with the central electrode operated with negative polarity. This mode of operation would direct the deuteron beams of a few hundred keV energy which are known to be generated in PF devices, towards the central electrode. The neutron yield in every shot was recorded with the help of a bank of calibrated activation type silver cathode Geiger Muller counters located close to the device. Typically with ~3 kJ of stored energy, $10^7$ neutrons were produced in each normal shot i.e. when the central electrode is used as anode. In the polarity reversed mode of operation also neutrons were produced but the magnitude of the neutron burst was an order of magnitude smaller.

In view of the special role of Ti in $D_2$ gas loaded cold fusion experiments, the Ti electrode was tested for induced radioactivity using autoradiography immediately after the experiment on two consecutive nights ($4^{th}$ and $5^{th}$ Jan. 90). No image was found at that time. But five weeks later (on $9^{th}$ Feb 90) using a new NaI detector set up it was discovered that a surprisingly high activity of ~392 μCi (~$10^{16}$ atoms of tritium) had built up on the surface of the Ti electrode which had been exposed to the plasma focus shots. To confirm this, the rod was subjected to overnight autoradiography once again. As seen in Fig. 16 a very beautiful and impressive image was obtained. This image has since been reproduced several times through repeated autoradiographic



continued until 17.45 hrs on Wednesday $14^{th}$ June when the cell was put off. A couple of hours later there was another small neutron burst lasting ~15 minutes. (These small bursts are shown plotted in Fig. 1 of the companion paper from BARC /6/.) But on the evening of Friday $16^{th}$ June, there was a large neutron burst (> $10^6$ neutrons) lasting for a couple of hours, (see Fig. 3)

The week long experiment was terminated at this point but the electrolyte was left in the cell and the $D_2$ gas plenum closed leaving the gas at an excess pressure of ~1kg/cm$^2$ above atmospheric pressure. Samples of electrolyte were drawn every day during the week of the experiment and sent for tritium analysis. The sample drawn on $23^{rd}$ June indicated a high tritium level of 121 nCi/ml (4.5 kBq/ml). After a lapse of about a month the tritium level in the electrolyte was found to have further increased to a value of ~460 nCi/ml (17 kBq/ml), a four fold increase since the termination of the experiment. Fig. 3 shows the variation of tritium concentration during the entire course of Run No. 2. It may be noted that after the large neutron burst the tritium level has shown a thousand fold jump suggesting that tritium is produced at the same time as the neutrons.

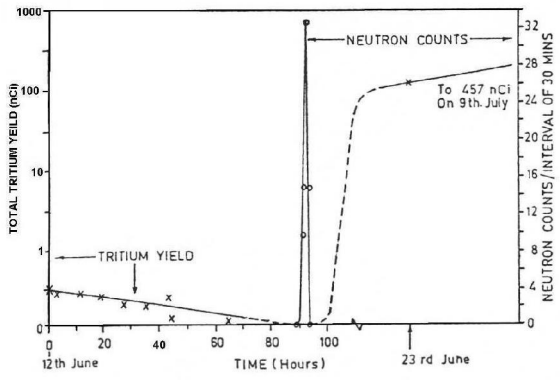


**Fig. 3. Neutron and Tritium Output During Run No. 2 of Milton-Roy Cell**

The integrated neutron yield during this experiment was ~$0.9 \times 10^7$ neutrons while the total number of tritium atoms generated was $1.9 \times 10^{15}$. The corresponding neutron-to-tritium yield ratio is $0.5 \times 10^{-8}$. This is in remarkably good agreement with the results of the earlier Milton Roy run, although the absolute neutron and tritium yields are lower by a factor of ~5. Thus the Pd-Ag cathode appears to have partly lost its capability to support "cold fusion reactions" after the first run.

## 2.3 FIVE MODULE CELL WITH DISC ELECTRODES /5/

This modular five unit cell represents our early attempts at obtaining experience with an electrolyzer design which can be scaled up to higher capacities if required. Five cathode discs each of 78 cm$^2$ area and 1 cm$^3$ volume are fabricated out of Johnson & Matthey palladium (75%)-silver (25%)-alloy sheets (0.12 mm thickness); the anode plates are made of porous nickel. The individual modules of the cell are clamped together and connected in series. Fig. 4 gives a schematic sectional view of the cell. The cell is capable of operating at currents of up to

## 7.5 OBSERVATION OF HIGH TRITIUM LEVELS IN AGED DEUTERATED Ti TARGETS/5/

The Division of Radiological Protection of BARC had procured a number of deuterated titanium targets on copper backing during 1972 to 1981 for dosimetry studies with accelerator based neutron sources. Twelve such targets were available, nine procured from M/S Amersham International of U.K. and the remaining three from the Isotope Division of BARC. In view of the various studies involving deuterated titanium targets described in the earlier sections, it was conjectured that cold fusion reactions might have occurred in these "aged" targets over the past 9 to 18 years and if so, it was argued, they should contain considerable amounts of tritium. In order to check this hypothesis these aged targets were subjected to various studies for establishing the magnitude of tritium in them. Five different techniques namely autoradiography, Ti K X-ray counting with NaI and high purity germanium detectors, $\beta$ counting with proportional counters and current measurements with an ionization chamber were used. The details of the targets, measurements and results are described in Ref /5/. It was found that the absolute tritium content in the targets varied between 0.3 and 150 MBq. Inquiries with the suppliers of these targets indicate that while inadvertent contamination during manufacture to the extent of a few hundred Bq is in principle a likely possibility, contamination levels in the MBq region is difficult to explain. The tritium levels in these aged TiDx targets expressed in terms of the (T/D) isotopic ratios was seen to vary in the range of 0.07 to $3.5 \times 10^{-4}$. For comparison the tritium activity of the $D_2O$ moderator of a CANDU type power reactor is almost 30 Ci/l even at saturation, corresponding to a (T/D) ratio of $10^{-5}$. In contrast the (T/D) ratio of fresh $D_2O$ from a factory is typically in the region of $10^{-14}$ to $10^{-13}$ only. Hence the authors are inclined to speculate that a plausible explanation for the unexpectedly high tritium levels in aged deuterated Ti targets could be the occurrence of cold fusion reactions.

## 8. MEASUREMENT OF TRITIUM LEVELS IN AQUEOUS AND METALLIC SAMPLES

As a consequence of the many years of operational experience with heavy water moderated research and power reactors in India, considerable expertise has been built-up in the area of tritium measurements, particularly in moderator and coolant circuits as well as in environmental samples. The status of development of the field of "Tritium Measurement and Applications" was reviewed recently at a Symposium /17/ held in Bombay to mark the golden jubilee of the discovery of tritium in 1939.

### 8.1 Analysis of Aqueous Samples

The tritium levels in the electrolytes and other aqueous samples was measured by expert groups at the Isotope and Health Physics Divisions of BARC. Commercial liquid scintillation counting systems such as Packard Instruments Model 4530 or LKB Systems Model 1215 (RACKBETA-II) which provide automatic quench correction facilities were employed. $^{40}K$ free vials were used. Commercially available scintillation cocktail, INSTAGEL, was found rnosff suitable as it, gave minimum chemiluminiscence. Double distilled water was used for diluting samples to reduce PH level as well as quenching impurities. In some electrolyte samples chemiluminiscence effects entirely masked the true tritium signal. Fig. 17 shows the



## 2.2 MILTON ROY COMMERCIAL ELECTROLYZER /5/

A diffusion type water electrolyzer using Pd-Ag alloy tubes as cathodes designed to generate ultra pure (oxygen free) hydrogen gas had been procured from the Milton Roy company of Ireland, sometime in 1988 for the purpose of generating $D_2$ gas for use in Plasma Focus experiments. Thus it so happened that when news of the cold fusion phenomenon reached Trombay in March 1989, this cold fusion cell was all set to be switched on with $D_2O$ as electrolyte. 5M NaOD in $D_2O$ was selected as the electrolyte based on the recommendation of the suppliers of the Milton Roy cell. A schematic view of this cell is shown in Fig. 1. The outer nickel body along with a central Ni pipe serve as coaxial anodes. The cathode comprises of 16 numbers of specially activated Pd-Ag alloy membrane tubes having a total surface area of 300 $cm^2$. These tubes are sealed at the top and open at the bottom into a plenum through which the $D_2$ (or $H_2$) gas is drawn.

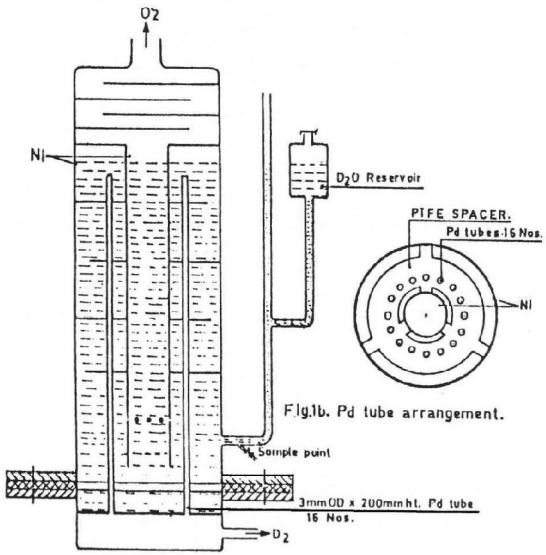


**Fig. 1. Schematic View of Milton-Roy Commercial Electrolyzer**

$D_2O$ of >99.75% isotopic purity, containing ~0.075 nCi/ml (or ~2.8 Bq/ml) of tritium and moisture free Na were employed for preparing the NaOD electrolyte. The electrolyzer can be operated up to a current level of 100 amps corresponding to a current density of ~330 mA/$cm^2$, although for continuous operations only 60 amps is recommended in order to avoid overheating.

**Run No. 1 (21st April 1989)**

The cell was initially operated for about 48 hours with 20% NaOH in ordinary water. It was later flushed with $D_2O$ and filled with 20% NaOD solution in $D_2O$ prior to commencement of electrolysis on 21st April 1989. Following brief operation at 30 amp, the current was slowly raised to 60 amps. After about 3 hours at this current level both the neutron detectors viewing the

### 8.3 Autoradiography

As mentioned already the technique of auto radiography has been employed very effectively at BARC to study the spatial distribution of near surface tritium produced in deuterated Ti and Pd targets. In order to obtain good resolution the samples were kept in contact with medical X-ray film and exposed overnight. The fogging of the film is due to the combined effect of tritium $\beta$ and the K X-rays excited in the host metal lattice. Sometimes a stack of two films was mounted close to the sample and it was observed that the second film also gives a similar but fainter image, ruling out the suspicion that image formation could be due to mechanical (scratching of films) or chemical reduction effects.

## 9. CONCLUSIONS

Experiments carried out by a number of totally independent groups employing diverse experimental set ups have unambiguously confirmed the production of neutrons and tritium both in electrolytically loaded and gas loaded Pd/Ti lattices.

Tables I & II present in a nut shell the main results of the BARC electrolysis experiments. It may be noted that in all 22 cells/experiments have yielded excess tritium varying over a wide $10^{10}$ – $10^{16}$ atoms. Roughly half of these may be described as having been "doubly successful" since in these both neutrons and tritium were measured. The main conclusions to emerge from the electrolysis experiments may be summarized as under:

(a) The most important observation is the surprisingly low neutron-to-tritium yield ratio, first reported by us at the Karlsruhe meeting in July 1989 /3/. 8 out of the 11 doubly successful cells of Table I have given values in the region of $10^{-6}$ to $10^{-9}$ for this ratio, while two experiments have given a comparatively larger value of $10^{-3}$ to $10^{-4}$. These ratios may be considered as overestimates since in most of the experiments the tritium escaping with the electrolytic gases has not been accounted for.

(b) The Trombay electrolytic experiments have also convincingly demonstrated that both neutrons and tritium are generated concomitantly. This is evident from the sharp increase in the tritium concentration of the electrolyte immediately after a large neutron burst in several of the experiments.

(c) Another significant observation pertains to the specific charge passed per unit of cathode surface area, namely amp-hrs/cm$^2$ at the time of the first neutron burst. This quantity which may be called the "switching on charge" is seen to be in the range of 0.6 to 3.2 amp-hrs/cm$^2$ in 8 out of the 11 experiments of Table I. In the remaining three cells (all of which have used LiOD as electrolyte) the switching on charge is an order of magnitude or more higher.

(d) It is significant that in all the five experiments which used 5 M NaOD as electrolyte the switching on charge was $\leq 3$ amp-hrs/cm$^2$. In the isolated instance where $Li_2SO_4$ was used the switching on charge was the lowest namely 0.15 amp-hr/cm$^2$ among all the experiments reported in Table I.

(e) In 8 out of the 11 cases of Table I the first neutron burst has occurred on the very first day of electrolysis, in fact within 9 hrs of commencement of electrolysis (except for experiment #7 where it occurred after ~24 hrs). This seems to be a unique feature of the Trombay results.



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# OVERVIEW OF BARC STUDIES IN COLD FUSION

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## ABSTRACT

A wide variety of experiments have been carried out by twelve independent teams employing both electrolytic and gas phase loading of deuterium in Pd and Ti metals to investigate the phenomenon of cold fusion first reported by Fleischmann and Pons in March 1989. The experiments were primarily devoted to the study of the emission of nuclear particles such as neutrons and tritium with a view to verify the "nuclear origin" of cold fusion. In 22 different electrolytic experiments whose cathode surface areas ranged from 0.1 to 300 cm$^2$, large bursts of neutrons and/or tritium were measured. Some of these gave clear evidence that these two nuclear particles were being generated simultaneously. The neutron-to-tritium yield ratios in the majority of these experiments was in the range of $10^{-6}$ to $10^{-9}$. The specific neutron and tritium yields expressed per cm$^2$ of cathode surface area also fitted into a systematic pattern. A unique feature of the BARC electrolysis results is that the first bursts of neutrons and tritium occurred (in 8 out of 11 cells) on the very first day of commencement of electrolysis, when hardly a few amp-hrs of charge had been passed.

In gas phase studies copious neutron emission was observed in a Frascati type absorption/desorption mode experiment with Ti shavings. Presence of tritium in $D_2$ gas loaded Pd and Ti samples was established through the technique of autoradiography as well as Ti K X-ray counting. In the case of Ti, it was noted that RF heating of samples, in lieu of resistance $\approx 10^{16}$ atoms of tritium had been "produced" on the top end surface of the central Ti electrode of a deuterium filled Plasma Focus device after it was subjected to ≈ 80 charge/discharges shots. All in all the BARC studies have unambiguously confirmed the anomalous production of neutrons and tritium in deuterium loaded Pd and Ti lattices.

## 1. INTRODUCTION

The announcement in March 1989 by Fleischmann and Pons /1/ of the occurrence of (d-d) fusion reactions (or possibly some other unknown nuclear processes) in Pd metal cathodes electrolytically loaded with deuterium, followed by reports of the observation of "2.45 MeV fusion neutrons" independently by Jones et al during the electrolysis of $D_2O$, resulted in a frenzy of activity the world over to reproduce these measurements. At Trombay several groups having expertise in various areas such as hydriding of metals, electrochemistry, isotope exchange

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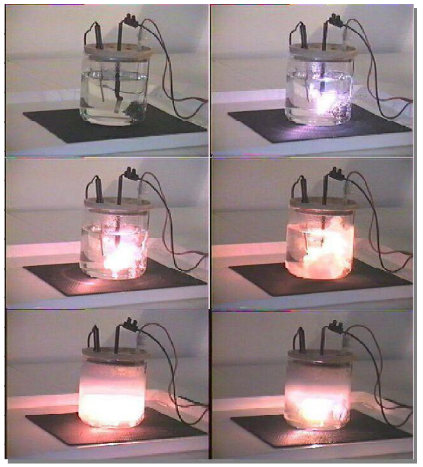
**OVERVIEW OF BARC STUDIES IN**

# COLD FUSION



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