MAIN APPLICATIONS OF ACCELERATORS, REACTOR AND IRRADIATION SOURCES

CYCLOTRON

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INTRODUCTION.

Cyclotron type accelerators are versatile irradiation sources with an increasing tendency of application in world scale Accordingly to informations from the International Conferences on Cyclotrons and their Applications(1) there are approximately 150 cyclotrons in the world, 80% of which entered in operation after 1960 and 50% after 1970, which shows the growing interest in the use of this type of accelerator in many research fields, as can be seen on Table I.

Table I - Applications of Cyclotron Accelerators

APPLICATION	APPLIC.DISTRIBUTION (%)	BEAM-TIME DISTR.(%)
Isotope Production	100	23.0
Basic Nuclear Physics	98	39,0
Development of Cyclotron	98	8.6
Bio-medical Applications	83	17.7
Solid State Phys.+ Mat.Science	54	5.1
Other Applications	15	5.4
Activation Analysis	2	1.2

Due to the fact that the majority of cyclotrons are used in multi-purpose mode, the sum of the application distribution is greater than 100%. The statistical time distribution shows that the cyclotrons are mainly used basic and applied plysical reseanch (Nuclear and Solid State Physics, plus Material Science-44.1%) and isotope production together with bio-medical applications (40.7%) It is interesting to point out that 98% of the existing cyclotrons are being improved in their performance and developed in their experimental capabilities. This demonstrates the concern of the users in updating their machines, as well as, the adaptability of these accelerators to new working conditions.

The beam-time distribution at IPEN-CNEN/SP gives a top priority to radioisotope production, with suitable time-sharing that allows materials irradiation. Presently Zinc is being irradiated with 24 MeV protons and 30 uA current for Ga^{67} production for nuclear medicine, together with $A\ell_2 O_3$ ceramic irradiation, for electrical resistivity measurements.

SPECIFICATION AND FACILITY DESCRIPTION.

The CV-28 is a compact multi-purpose irradiation source and is presently utilized in major research institutions and hospitals. Thus enabling the use and development of new characterization methods for nuclear materials and powerful dignostic methods in nuclear medicine and other activities listed on Table I. The model CV-28 was ordered at The Cyclotron Corp. in 1975, and installed in its especially designed building in 1980. The installation of the peripheral equipment consisting of: a) cooling system, b) electrical and electronic systems, c) vacuum system d) beam lines and e) shielding, was started at that date and proceeded until December 1983, when the cyclotron became operational. It has a total capacity for seven external beam lines , plus one in external target: presently two external target stations are operational. Additional beam lines can be installed accordingly to research and development demand. The IPEN 91 cm cyclotron produces high quality external beams as shown in Table II, whith the manufacturer's nominal data.

Table II

PARTICLE	EN.RANGE(MeV)	EXTERNAL CURRENT (μA)		INT.CURRENT(μA)
		Emin.	E max.	
Protons	2-24	40	60	200
Deuterens	4-14	50	100	300
Helium -3	6-36	5	50	135
Helium -4	8-28	6	40	90

Tolerance: ± 0,5 MeV at Emin, and ± 1.0 MeV at Emax.
Energy Resolution: 0,5 ou 50 KeV (whichever is greater)

The geometry of main components, at median plane cross section is shown in Fig.1. Further specifications are: pole tip diameter of main magnet 96.50 cm; average magnetic field 1.74T (17.4 KG): weight of the cyclotron 22.8 tons. The ions are generated in P.I.G. source and are accelerated by two 90 degree Dees. The ion source consists of ion-heated cathods which eliminates the necessity of filaments and respective power supply. The Dees are connected through vacuum insulators to an inductor assembly located in the Radio-Frequency system. The RF operation frequencies are selected by displacing the inductor to the correct impedance and lenght. The magnetic field of the CV-28 model is shaped by three hill sectors with four sets of profile coils to provide for adequate field profile for isochronous acceleration of ions. The pole tips of main magnet form the upper and lower covers of vacuum chamber. This construction permits the upper half of the cyclotron to be raised for access to the acceleration region for maintenance. The internal ion beam can be intercepted, at any radius, by the beam probe located inside the vacuum chamber. During extraction the beam is deflected by an electrostatic chanel (deflector) positioned between the Dees, passing afterwards through a focussing magnetic channel, before leaving the cyclotron at exit port. Two sets of three harmonic coils are located radially inside the acceleration region to provide for the centering of the beam in the cyclotron.

The support equipment is composed of: Anode Power Supply (PS) (6 A; 0-12 KV DC); Magnet P S (0-230 A DC); and Deflector, Dee Bias, Ion source, Profile and Harmonic coils power supplies, plus hydraulic, pneumatic, cooling (air conditioning and water) and demineralized water, systems. The cyclotron building contains 18 rooms for laboratories, staff, peripheral equipment and control. Additionally there are heavily shielded areas including the cyclotron room and three experimental areas. Besides the constant operational parameter optimization, some technical improvements are programmed, such as, installation of a second diffusion pump at the vacuum tank (acceleration region) and an external beam-scanning device to guarantee a homogeneous sample irradiation.

Alpha Particle Implantation - Simulation Experiments. (5,6)

An advantage of cyclotron use in Radiation Damage study is that some hours of alpha particle implantation can simulate many years of fast neutron irradiation in a reactor core. (2) These experiments are complemented by microhardness, electrical resistivity , magnetic after-effect and optical and electron microscopy.

Alpha particle implantations were performed on 316 stainless steel to simulate the (n,α) reaction of nuclear reactors which produces bubbles, swelling and embrittlement as destructive consequences. The critical effect of He gas, produced by (n,α) reaction, is the fast degeneration of the mechanical properties of metals and alloys. Mechanical properties changes are evaluted by means of creep measurements at temperatures up to 750º C, in controlled atmosphere with the aim of reproducing the severe working conditions of power reactors. (2,3,4) The study of these detrimental effects becomes important in:

a) selection of more adequate materials, by characterization of presently available materials, and

b) search for new more radiation-damage resistant alloys.

Two experimental series were performed with different conditions of: applied stress, temperature, He implanted doses and fast neutron irradiation. Creep $\dot{\varepsilon}$ is a perameter strongly dependent on temperature T and activation energy Ea, $\dot{\varepsilon} \propto \exp\ (Ea/kT)$. The first experimental series consisted of ten samples, 100 µm thick with 50% cold work . Three samples (I-1, 2 and 5) were fast neutron ($E \geq 1$ MeV) irradiated inside IEA-R1 reactor core with a fluence of $1,7.10^{18} n/cm^2$; four samples (AI-1 2,3 and 4) were homogeneously He implanted at concentrations of 5 and 26 appm in CV-28 cyclotron and the rest (samples 20,25 and 29) were control samples. The creep behaviour of the samples is shown in Figs. 2 and 3.

The second experimental series consisted of ten samples with 100 MPa applied stress, divided in two lots:

1st. - 7 samples annealed during 2 hours at 1,050ºC in vacuum better than 10^{-5} Torr.

2nd. - 3 samples 20% coldworked after the annealing, with the results shown in Fig. 4.

Neutron irradiated samples (Fig.2), except for the lower rupture point, have almost coincident creep behaviour. On the other hand (Fig.3), a marked difference can be seen ou He implanted samples by the decrease in rupture time and ductility, showing that embrittlement occurs even by small He concentrations. The results offer an experimental evidence of the intense embrittlement due to the presence of He in the material structure.

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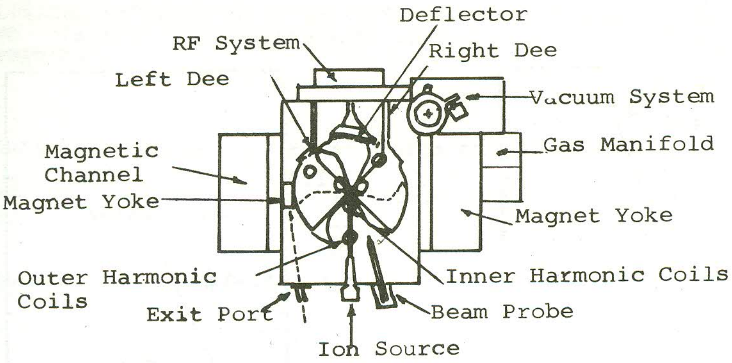

Fig.1-Median plane cross section of cyclotron CV-28.

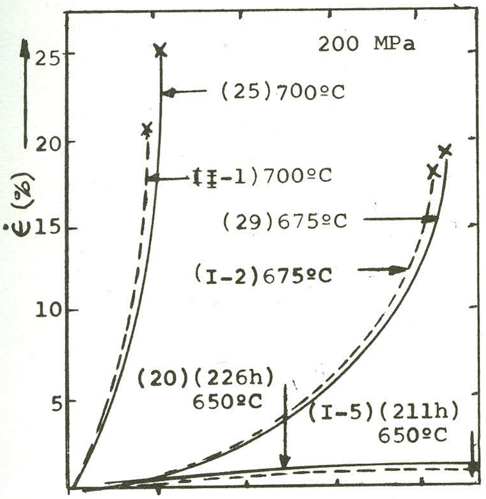

Fig.2-Creep behaviour of control samples (20,25,29) and fast neutron irradiated samples (I-1,2,3).

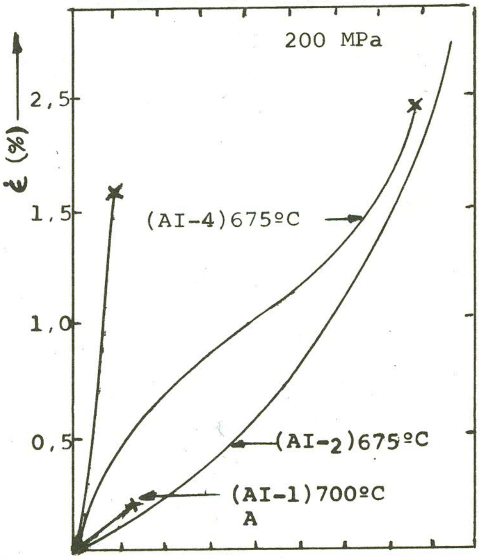

Fig.3-Creep curves of Helium implanted samples with 5 appm (AI-3,4) and 26 appm (AI-1,2) in cyclotron.

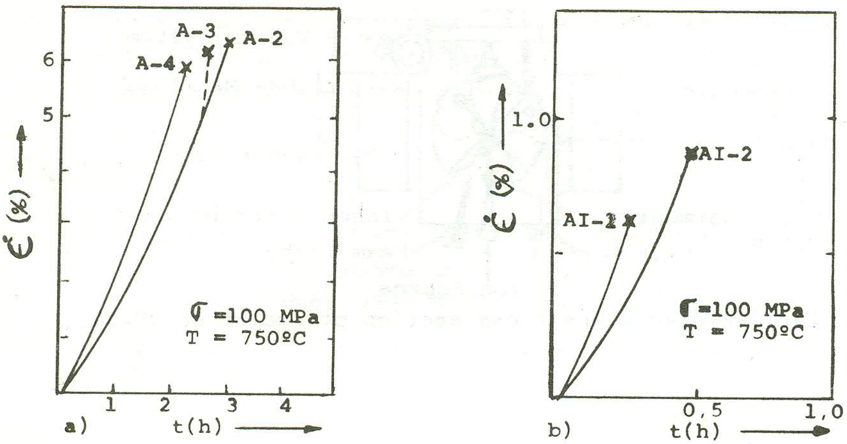

Fig.4-Creep curves: a)annealed samples-b)annealed and 26 appm He implanted samples.