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Medical Proton Accelerator Project

M.N.H. Comsan
Nuclear Research Centre, Atomic Energy Authority,Cairo, Egypt

Abstract

A project for a medical proton accelerator for cancer treatment is outlined. The project is motivated by the need for a precise modality for cancer curing especially in children. Proton therapy is known by its superior radiation and biological effectiveness as compared to photon or electron therapy. With 26 proton and 3 heavy-ion therapy complexes operating worldwide only one (p) exists in South Africa, and none in south Asia and the Middle East. The accelerator of choice should provide protons with energy 75 MeV for eye treatment and 250 MeV for body treatment. Four treatment rooms are suggested: two with isocentric gantries, one with fixed beams and one for development. Passive scanning is recommended. The project can serve Middle East and North Africa with ~ 400 million populations. The annual capacity of the project is estimated as 1,100 to be compared with expected radiation cases eligible for proton cancer treatment of not less than 200,000.

Introduction

Proton therapy is a modality for treating cancer cells through localized deposition of controlled amount of radiation energy within tumor region. The method uses the distinct feature of heavy charged particle interaction with matter, namely that they have a well defined penetration range and concentrated deposition of energy at the end of this range. This gives rise to the so called Bragg peak. Superiority to photon energy deposition is evident, as the later has nearly exponential fall off with depth. With a single proton beam it is possible to tailor the energy deposition (dose) not only in the lateral direction but also as a function of the depth in patient. Research on proton (and ion) beams has been ongoing for almost half a century with about 52,000 patients been treated. Proton facilities are becoming more numerous, with several located in hospital settings. The majority of proton and ion radiation therapy facilities are operating in EU (9), Japan (7), USA (6) and Russia (3). The main obstacles for wide spread use of these facilities are the size and cost ranging between 80 M Euros for proton and 200 M US$ for ion facility, respectively.

Need for Radiation Therapy

Cancer is the 2nd cause of death after heart disease contributing to ~ 23% of all deaths in developed countries. According to American Cancer Society statistics some 563,700 die from the disease in 2004. Nowadays cure from cancer is achieved for 45% of all cancer patients using the currently available therapeutic strategies: surgery, radiation therapy and chemotherapy. With the tumor detected in its early stages and still well localized the use of local therapies such as surgery and radiation therapy offer the patient a reasonably good chance of survival and cure. About 50% of all cancer patients receive radiation therapies during the course of their treatment mostly by external beam therapies. Experience showed that radiotherapy is the modality of choice for localized inoperable tumors. As palliative care radiation therapy can be used to shrink tumors and reduce pressure, pain and other symptoms of cancer. Many cancer patients find that they have a better quality of life when radiation is used for this purpose.

Rationale of Proton Therapy

Clinical use of proton radiation therapy started more than 50 years ago practically simultaneously in USA, Sweden and Soviet Union in physics centres having high energy proton accelerators. Broad experience has been accumulated in the construction and use of dedicated treatment units for irradiation and dose delivery systems making it possible to irradiate tumors practically in any part of the body. Combined with modern computer diagnostics that provide accurate and precise determination of tumors and other pathologic structures, proton therapy provides their efficient treatment.

In view of their excellent dose profile, proton therapy is recommended for tumors with the following characteristics:

- Have localized evolution (with low metastatic tendency).
- Cannot be totally removed surgically.
- Need high doses of radiation to cure (often >70 Gy).
- Lie very close to radiosensitive organs or tissues.

Particular success has been found in the treatment of uveal (or ocular) melanomas, prostate cancer, and the post operative management of base of the skull and spinal canal malignancies. World wide eye treatment contributes ~ 45% of all proton therapy treatments with ~ 95% cure. Proton therapy is particularly appropriate for treating tumors in children where great emphasis is placed upon reduction of any irradiation of normal tissues to prevent serious complications and reduce incidence of secondary tumors.

Beam Delivery

Protons accelerated in modern high energy accelerators are well defined both in geometry and energy. The size of accelerated proton beams are usually quite small (≤10 mm in diameter) and the Bragg peak region of monoenergetic beams is narrow (≤20 mm FWHM). Because of tumor finite extension, the beam has to be modified to deposit the required dose over the whole 3-D target volume. Two methods are used for beam shaping: the passive scattering (producing broad beams) or the dynamic beam scanning (using pencil beams). Modulating broad and pencil beams in depth involves the superposition of suitably weighted beams of different energies (ranges) that results in uniform depth dose over the target volume. Either of the technique has its advantages and disadvantages. Because of its inherent capabilities and in spite of current difficulties (which can be improved with increasing clinical practices), scanned beam method is getting wider acceptance as the technique of choice for the future. Table (1) summarizes comparison between the two techniques.

Table 1. Comparison between beam delivery methods.

Scattering	Scanning
Mature technology	New technology
Insensitive to organ motion	Very sensitive to organ motion
Inflexible	Very flexible
Field specific hardware required	No field specific hardware required
Large gantries required	Smaller gantries can be used

Proton Therapy Facilities in Operation

The total number of proton and ion facilities currently in operation is 29, three of them are heavy-ion facilities. The facilities are distributed over 13 countries. Most of the facilities are located within the premises of nuclear research centres. However, of the most newly constructed facilities are dedicated facilities attached to hospitals. First of the dedicated facilities was that of the Loma Linda University starting routine operation in 1990. Loma Linda Proton Therapy Centre. For a long time this centre was the model for other centres to follow. Tables 2-6 give data available on proton and ion therapy facilities operating world wide. Abreviations in the tables are: * - for degraded beam and + - for beam scanning. As is clear from the tables, the total number of treated patients is 52470 as of March 2007.

Table 2. Facilities in European Union.

Facility	Country	Machine	Particle	Energy	Direction	Start	Patients	Date
PSI, Villigin	Switzerland	Cyclo.	p P^+	72 230^*	Horiz. gantry	1984 1996	4646 262	Dec.06
Uppsala	Sweden	Synch.	P	200	Horiz.	1989	738	Dec.06
Clatterbridge	England	Cyclo.	P	62	Horiz.	1989	1584	Dec.06
Nice	France	Cyclo.	P	65	Horiz.	1991	3129	Sep.06
Orsay	France	Synch.	P	200	Horiz.	1991	3766	Dec.06
GSI, Darmstadt	Germany	Iso.	ion$^+$, C	430/u	Horiz.	1997	316	Jul.06
HMI, Berlin	Germany	Cyclo.	P	72	Horiz.	1998	829	Dec.06
INFN-LNS, Catania	Italy	Synch.	P	60	Horiz.	2002	114	Oct.06

Total EU facilities operating 9, total patients treated 15384.

Table 3. Facilities in Japan.

Facility	Province	Machine	Particle	Energy	Direction	Start	Patients	Date
HIMAC	Chiba	Cyclo. Synch.	p ion, C	90 400/u	Horiz. Hor, Ver	1979 1994	145 2867	2002 Aug.06
PMRC (1) PMRC (2)	Tsukuba	Synch.	p	250^* 250	Hor, Ver. Gantr.	1983 2001	700 930	2000 Jul.06
NCC	Kashiwa	Cyclo.	p	235	Gant, Hor	1998	460	Nov.06
HIBMC	Hyogo	Synch.	P ion, C	230 320/u	Gant, Hor Hor,Ver45	2001 2002	1099 131	Sep.06 Sep.06
WERC	Wakasa	Synch.	p	200	Hor, Ver	2002	33	Aug.06
	Shizouka	Synch.	p	230	Gant, Ver	2003	410	Nov.06

Total Japan facilities operating 7, total patients treated 6775.

Table 4. Facilities in USA.

Facility	State	Machine	Particle	Energy	Direction	Start	Patients	Date
Harvard U., Boston	MA	Cyclo.	p	160	Horiz.	1961	9116	2002
Loma Linda	CA	Synch.	p	250	Gant, Hor.	1990	11414	Nov.06
MPRI(2)	Indiana		p	200	Horiz.	1993	220	Sep.06
UCSF	CA	Cyclo.	P	60	Horiz.	1994	920	Mar.07
NPTC,MGH Boston	MA	Cyclo.	p	235	Gant, Hor.	2001	2080	Oct.06
MD Anderson	Texas	Synch.	p	250	Gant, Hor.	2006	114	Dec.06
FPTI, Jacksonville	FL	Cyclo.	p	230	Gant, Hor.	2006	15	Dec.06

Total USA facilities operating 6, total patients treated 23879.

Table 5. Facilities in Russia.

Facility	City	Machine	Particle	Energy	Direction	Start	Patients	Date

ITEP	Moscow	Synch.	p	200	Horiz.	1969	3927	Dec.06
	St. Peters burg	Synch.	p	1000	Horiz.	1975	1320	Oct.06
JINR	Dubna	Phaso.	p	200^*	Horiz.	1999	318	Jul.06

Total Russia facilities operating 3, total patients treated 5565.

Table 6. Facilities in Other Countries.

i) South Africa

Facility		Machine	Particle	Energy	Direction	Start	Patients	Date
iThemba Labs, Faure	Cape Town	Cyclo.	p	200	Horiz.	1993	486	Dec.06

ii) Canada

Facility	City	Machine	Particle	Energy	Direction	Start	Patients	Date
TRIUMF	Vancouver	Cyclo.	p	72	Horiz.	1995	111	Sep.06

iii)China, PR

Facility		Machine	Particle	Energy	Direction	Start	Patients	Date
WPTC	Zibo	Cyclo.	p	230	Gant, Hor.	2004	270	Jul.06

iv) Korea, R. of

Facility	City	Machine	Particle	Energy	Direction	Start	Patients	Date
NCC	Seoul	Cyclo.	p	235	Gant, Hor.	2007	---	----

Total other countries facilities operating 4, total patients treated 867.

Facilities under Construction and Planned

Table 7 summarizes data available on proton therapy facilities which are under construction or planned. Concentration was made on hospital adapted facilities.

Table 7. PT Facilities under Construction and Planned

Facility	Country	Machine	Particle	Energy	Direction	Status	Start
Rinecker, Munchen	Germany		p^+	250	Gant, Horiz.	Under construction	2007
PSI, Villigen	Switzerland	Cyclo..	p^+	250	Gant, Horiz.	Under construction	2007
CNAO, Pavia	Italy	Synch..	p ion	400/u	Hor, Ver..	Under construction	2008
iThemba Labs	S. Africa	Cyclo.	p	230	Gant, Horiz, Ver. 30°	Under construction	2008
Med. Austron	Austria	.	p ion		Gant, Horiz.		
Rinecker, Cologne	Germany		p^+	250	Gant, Horiz.		
Penn Univ., PA	USA	Cyclo.	p	235	Gant, Horiz.		2009
IMP, Lanzhou	China	Synch.	p, C ion	220 100/u			
UCBL, Lyon	France	Synch.	p^+, C^{6+}	220 400/u	Gant, Horiz,Ver.	Planned	
Cannizaro, Catania	Italy	SC Cyclo	p, ion		Gant, Horiz		2009

Proton Therapy Facility for Egypt

With ¬ 76 millions population and current world average of cancer incidence of 4.5915x10^{-3}, it is expected to have in Egypt ¬ 350,000 new cancers yearly. There is a growing need for a facility to treat certain tumors that are difficult to treat using existing radiation treatment modalities as Co-60 gammas, mega-voltage x-rays or electron beams. The vision for the future aimed at is to treat ¬ 1% of the medical indications treated with conventional radiotherapy as compared to ¬ 10% world aim. .The facility of choice would be a PT facility based on a 250 MeV proton accelerator with full utilization of beam availability. Variable energy mode is to be chosen with necessary beam transport and switching systems, and 360° isocentric gantry(ies) with nozzles. A special care is to be directed towards system accurate, reliable and safe operation.

Facility Proposed Layout

A schematic layout of the proposed facility is shown in Fig. 1. The building has a high radiation area consisting of thick concrete walls with mazes as neutron shield. The layout is similar to many other layouts used for proton therapy USA, Germany, Italy and South Korea. Four treatment rooms are planned: two rooms with 360° gantries, one room for horizontal beam and a reserve room for future expansion. This room can house an inclied vertical beam line similar to that under test in South Africa.

With four operating rooms and based on experience with similar PT facilities worldwide, the number of patients undergoing PT treatment can reach 1,100/year. The number is well below the 1% goal mentioned before.

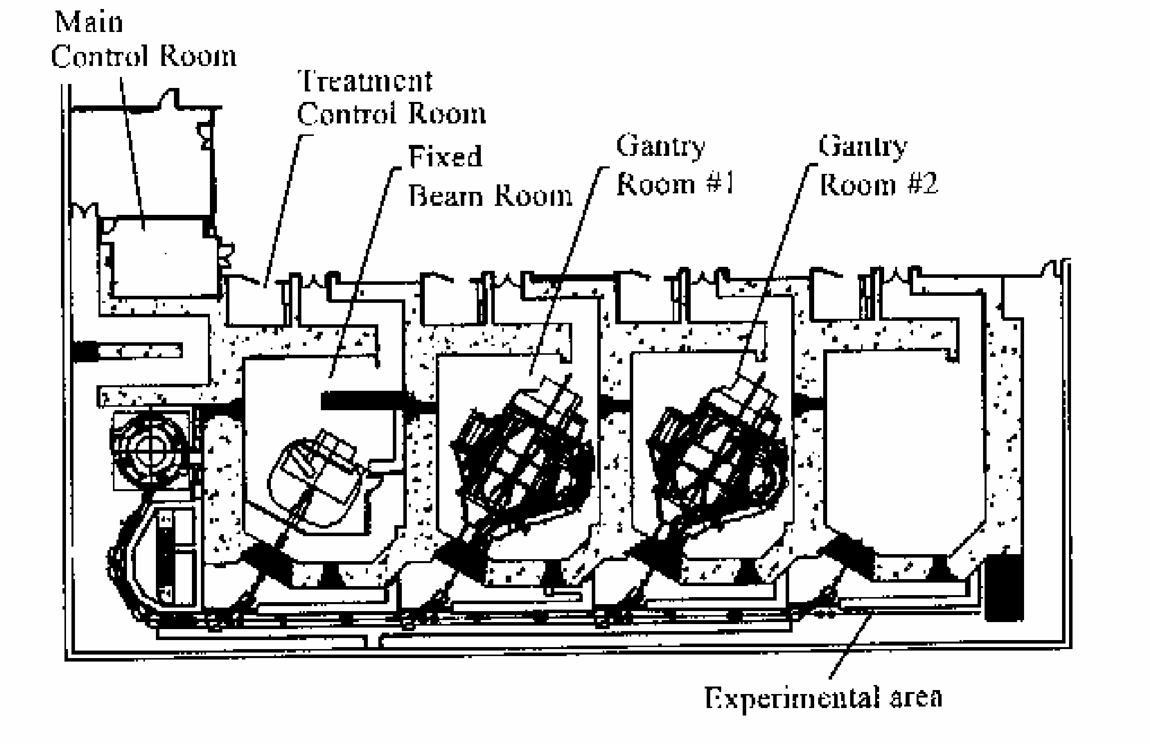

Fig. 1. Master plan proposed for Egypt's proton therapy facility.

Conclusion

Egypt has a long experience in accelerator operation and utilization. In 1961 a 2.5 MeV Van de Graaff accelerator was put in operation for basic nuclear physics research till 1974. In

1986 a 1.5 MeV electron accelerator was installed for use in industrial applications, and is in operation since 1996. In 1999 a k=20 AVF cyclotron started operation for multidisciplinary utilization in science and isotope production. Recently a 3 MV tandem accelerator for light and heavy ions is put in operation for basic and applied research. An in-hospital baby cyclotron is in operation since 2005 for medical F-18 production. Another in-hospital based baby cyclotron for PET production is under construction in Children's Cancer Centre. Several tens of megavoltage electron accelerators are in operation in state-owned and private hospitals for conventional cancer treatment since the sixties of last century, including recently utilized multi-leaf, intensity modulated systems. With this accumulated experience in accelerator operation and utilization it is just time for Egypt to look into the future, and think about the installation, operation and use of a PT facility for cancer treatment.

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Neutron Diffraction Measurements Using the CFDF for Studying theResidual Stress

R.M.A. Maayouf and Y.H.El-Shaer
Reactor Physics Dept., NRC, Atomic Energy Authority, Cairo, Egypt,

ABSTRACT

The present work presents the results of neutron diffraction measurements, performed using the Cairo Fourier Diffractometer Facility (CFDF) for studying the residual stress after welding. The CFDF has ~45% resolution and value of 1.1x 10^6 neutrons cm^{-2} s^{-2} of integral neutron flux at the sample position. The measurements were performed both for electric and argon welding; using steel and copper rods. It has been found from the present measurements that, the resulting diffraction spectra could be successfully used for studying the residual stress within wavelength range between 0.5-2.9 A^o.

Keywords: Neutron Diffraction / Residual Stress / Material Studies

INTRODUCTION

The de- Broglie wavelength of thennal neutrons is comparable to atomic spacing. Besides, neutrons are highly penetrating, as they have no charge, and they can be used for nondestructive study of bulk materials. Moreover, the presence of residual stress in engineering components can significantly affect their load carrying capacity and their resistance to fracture (1). Residual stress can be introduced into components during fabrication and also as a result of creep and plastic defonnation incurred during use. The manufacturing processes, which result with residual stress, are welding, forging, bending and machining operations. Thus, nondestructive neutron diffractometry, as one of the powerful tools, could be used for studying the defonnation; in materials, which due to stress. Several laboratories, at the time being, make use of the available neutron diffractometers for the evaluation of the residual stress in order to serve the industry (1-5). Preliminary measurements (6,7) where carried out, using the Cairo Fourier Diffractometer Facility (CFDF) in order to check the possibility of its use for studying residual stress.

The present paper presents the final results of neutron diffraction measurements, perfonned for stress analysis using the CFDF, for nonnal steel and copper samples; after argon and electric welding.

EXPERIMENTAL DETAAILS

The CFDF has been used for perfonning the present neutron diffraction measurements. The CFDF is mainly based on the reverse time of flight (RTOF) principle (8). A schematic diagram of the CFDF at the ET-RR-I reactor is given in Fig. I. Accordingly, neutrons emitted through in-pile collimator, from one of the ET - RR -1 reactor horizontal channels, are first guided by the main curved neutron guide (22 m length), then incident on the Fourier chopper. Neutrons after the Fourier chopper are collimated by an auxiliary straight neutron guide (3 m long) to the sample. Neutrons scattered from the sample at 90° are detected by the detector system. This scattering angle gives the best resolution in space localization of a sample scattering volume and could be used, with high efficiency, for studying the internal stresses in materials; along with neutron diffraction (9).

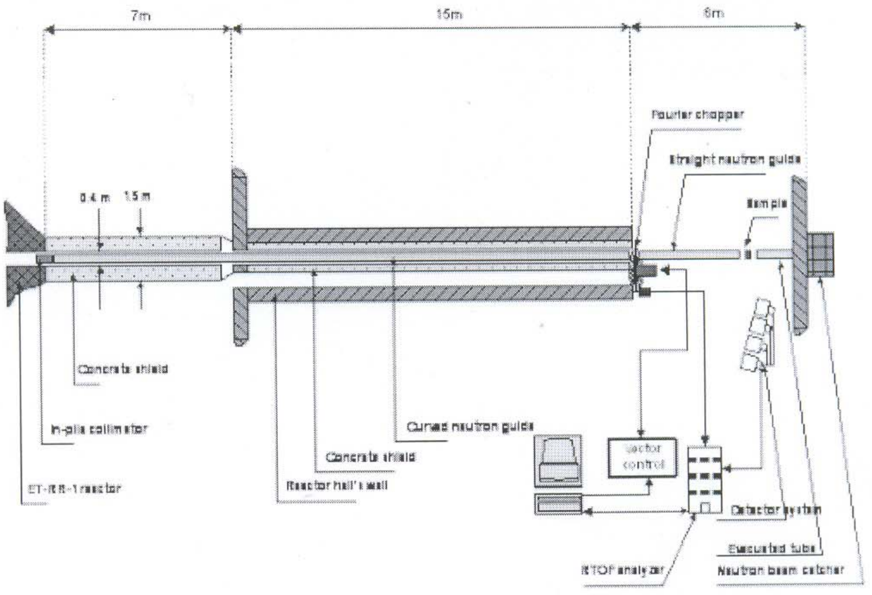


Fig.1: Schematic of the CFDF at the ET-RR-1 reactor.

Table 1: The CFDF parameters

Parameter	Value
λ (Å) range	1-4
D (Å) range	0.5-3.0
Φ_s (n / cm^2 s)	1.1x10^6
V_s(cm^3)	2.125
Resolution (%)	0.45%
Ω (Sterad)	0.051
Φ_s V_s Ω	1.2x10^5

The resolution of the CFDF was experimentally determined and found to be 0.45% for optimum diameter 5.5mm (ID). The main parameters of the CFDF are given in Table 1. More details about the facility can be found elsewhere (9, 11). The present measurements were performed for normal steel and copper rods; using both electric and argon welding. Accordingly five rods (5.5mm) in diameter were prepared, for each sample, and while two rods were electrically welded, the other two were welded using argon; the remaining rod was used as a free sample. The welding temperature of either argon or electric welding is > 1500 DC. The measurements were performed at the welding area, lcm and 2 cm distances from it for steel samples. For copper samples, the measurements were performed also at welding area, 2cm and 4cm distances from it. The measurements were carried out at room temperature, under the following set-up conditions of the CFDF; The Maximum rotation speed of the Fourier chopper: 8000 rpm, the frequency window is Gaussian with delay time of 2048-f..l sec., the RTOF multichannel analyzer is set at channel width of 2-f..l sec. The diffraction patterns obtained for both steel and copper are displayed in Figs. (2, 3).

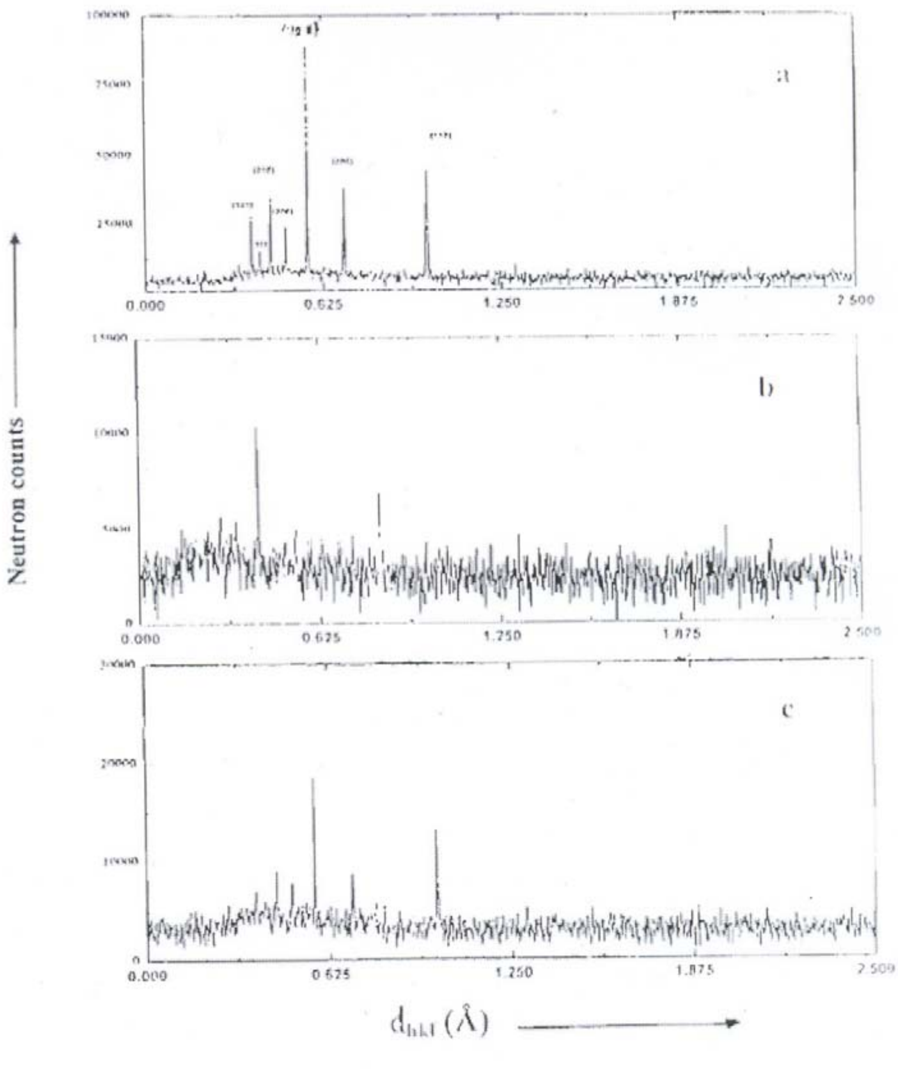


Fig. 2: The diffraction patterns of steel:
a) free sample; b) after argon welding;
c) after electrical welding

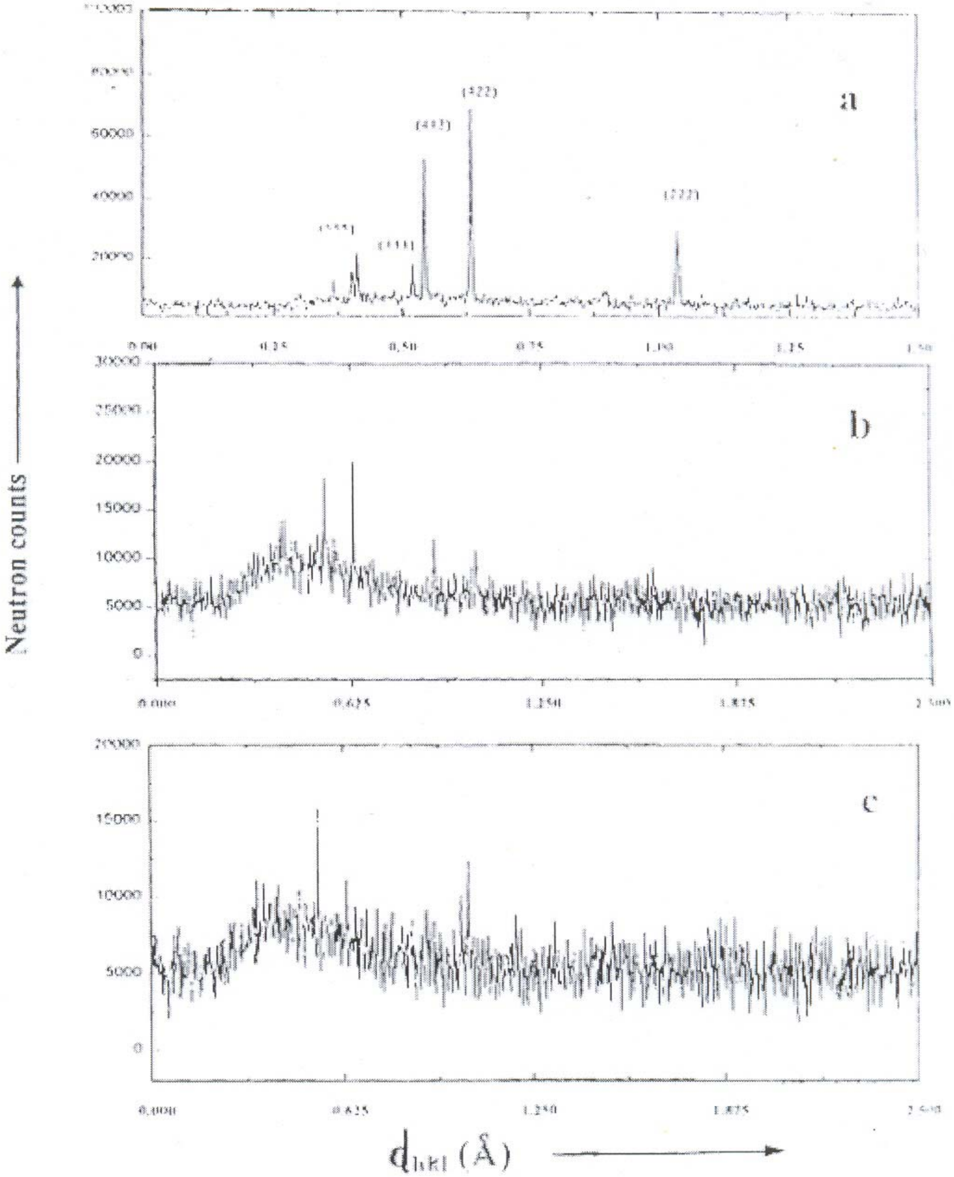


Fig.3. The diffraction patterns of copper:
a) free sample; b) after argon welding;
c) after electrical welding

RESULTS AND DISCUSSION

The internal 'lattice' stress presented in material is obtained from the measured elastic 'lattice' strain, which is determined (4) using Bragg's law:

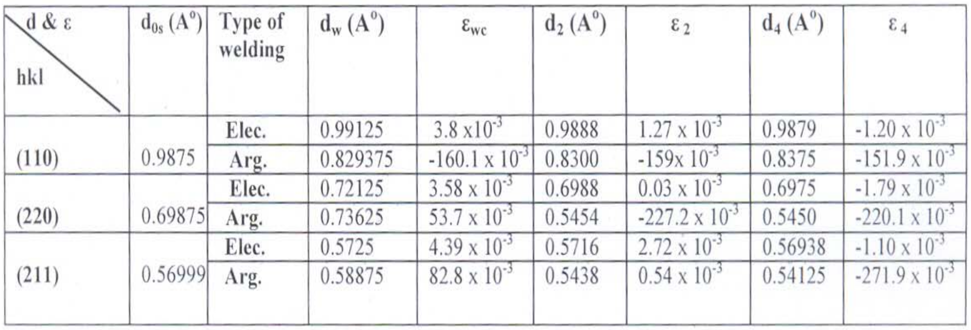
$$n\lambda = 2d_{khl} \sin\theta_{khl} \qquad (1)$$

where dhkl is crystal lattice plane, 8hkl is scattering angle, A is the neutron wavelength and hkl are Miller indices. The elastic strain, Ehkl is determined from the relative change between the measured and the strain- free lattice plane distances d and do respectively as follows:

$$\varepsilon_{khl} = \Delta\lambda/\lambda = \left(d_{khl} - d_{0khl}\right)/\, d_{0khl} \qquad (2)$$

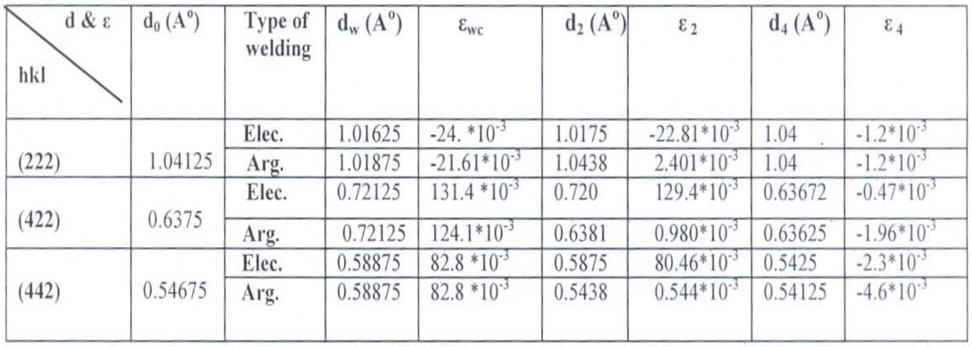
Where dOhkl is determined for the stress free sample (I) . Diffraction peaks were observed for steel at (110), (200) and (211) planes; for copper at (222), (422) and (600) planes. Fig. (4) represents the copper planes. These planes where chosen as they covered d- spacing values between 0.5-3 A. The strains were deduced from present measurements using eq.(2). The resulting values of strains are given in tables (2,3). Table 2 represents the resulting strain values of steel at the welding area, lcm and 3cm distances from it (lOws, £1, and £3) respectively. Table 3 represents the resulting strain values (Ewe, 102 and 104) of copper; at the welding area, 2cm and 4cm distances from it respectively.

Table (2): The resulting strain values of steel welded by electric and Argon.



d & ε / hkl	d_{0s} (A°)	Type of welding	d_w (A°)	ε_{wc}	d_2 (A°)	ε_2	d_4 (A°)	ε_4
(110)	0.9875	Elec.	0.99125	3.8×10^{-3}	0.9888	1.27×10^{-3}	0.9879	-1.20×10^{-3}
		Arg.	0.829375	-160.1×10^{-3}	0.8300	-159×10^{-3}	0.8375	-151.9×10^{-3}
(220)	0.69875	Elec.	0.72125	3.58×10^{-3}	0.6988	0.03×10^{-3}	0.6975	-1.79×10^{-3}
		Arg.	0.73625	53.7×10^{-3}	0.5454	-227.2×10^{-3}	0.5450	-220.1×10^{-3}
(211)	0.56999	Elec.	0.5725	4.39×10^{-3}	0.5716	2.72×10^{-3}	0.56938	-1.10×10^{-3}
		Arg.	0.58875	82.8×10^{-3}	0.5438	0.54×10^{-3}	0.54125	-271.9×10^{-3}

Table (3): The resulting strain values of copper welded by electric and Argon.



d & ε / hkl	d_0 (A°)	Type of welding	d_w (A°)	ε_{wc}	d_2 (A°)	ε_2	d_4 (A°)	ε_4
(222)	1.04125	Elec.	1.01625	$-24. {*}10^{-3}$	1.0175	$-22.81{*}10^{-3}$	1.04	$-1.2{*}10^{-3}$
		Arg.	1.01875	$-21.61{*}10^{-3}$	1.0438	$2.401{*}10^{-3}$	1.04	$-1.2{*}10^{-3}$
(422)	0.6375	Elec.	0.72125	$131.4 {*}10^{-3}$	0.720	$129.4{*}10^{-3}$	0.63672	$-0.47{*}10^{-3}$
		Arg.	0.72125	$124.1{*}10^{-3}$	0.6381	$0.980{*}10^{-3}$	0.63625	$-1.96{*}10^{-3}$
(442)	0.54675	Elec.	0.58875	$82.8 {*}10^{-3}$	0.5875	$80.46{*}10^{-3}$	0.5425	$-2.3{*}10^{-3}$
		Arg.	0.58875	$82.8 {*}10^{-3}$	0.5438	$0.544{*}10^{-3}$	0.54125	$-4.6{*}10^{-3}$

It is noticeable that the values of strain deduced for steel are the highest at the welding area, almost for all planes, when using electric welding. For argon welding the picture is the same, as for electric welding, only at the (211) plane; for copper it is noticeable that both weldings have the same behavior

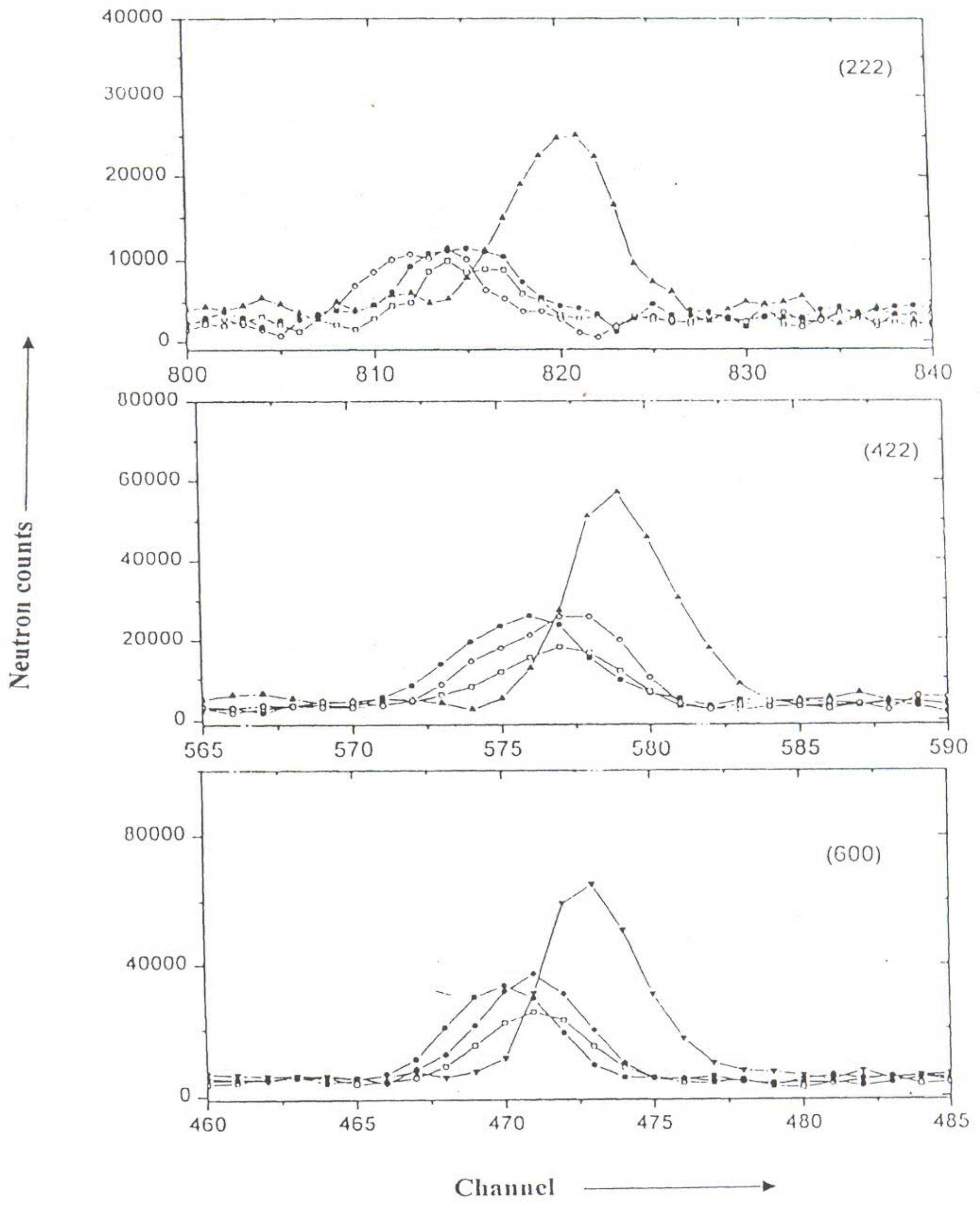


Fig 4: The observed copper peaks at different planes

except for the (222) plane. This might be due to the poor resolution at the plane position. It is concluded that the electric welding is more adequate for steel; for copper both electric and argon weldings could be used. Accordingly, the diffraction spectra measured by the CFDF could be successfully used for studying the residual stress after welding.

CONCLUSIONS

1- The CFDF could be successfully used to perform neutron diffraction measurements at considerable counting rates of the detector system in a relatively small time; significantly saving the measuring time.
2- The electrical welding is more adequate (for both steel and copper), than the argon one and the residual strain is less in case of electrical welding.

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