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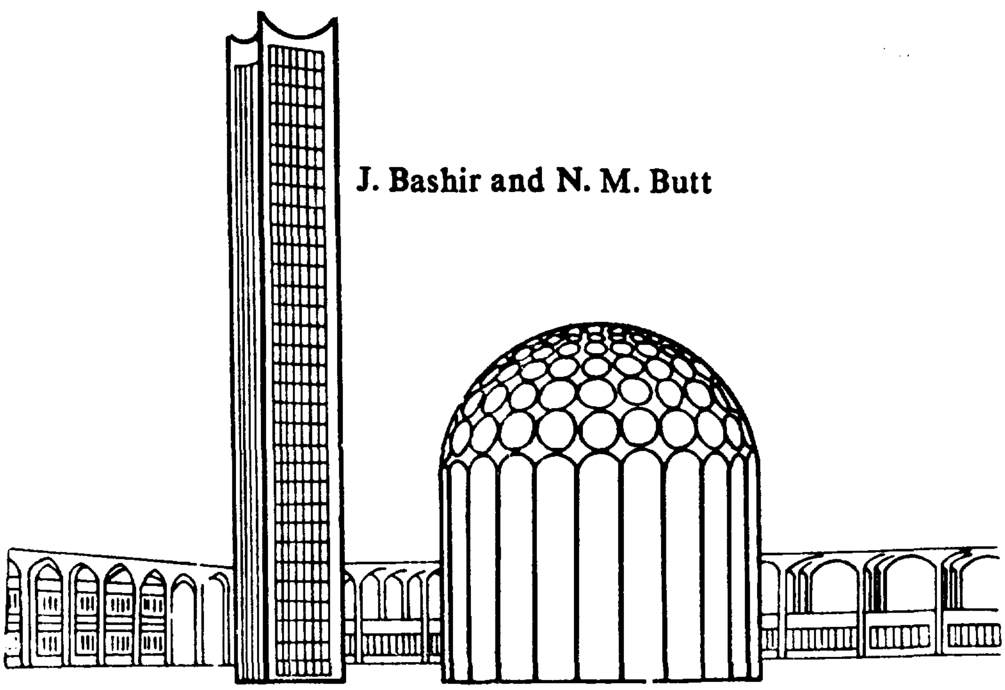
ENHANCEMENT OF RESEARCH REACTOR UTILIZATION IN THE DEVELOPING COUNTRIES*



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*Paper presented at the Consultant's Meeting on
Enhancement of Research Reactor Utilization
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VOL 2 ͗ № 0 4

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Abstract

As the research reactor represents a significant capital investment on the part of any institution and in addition there are recurring annual operating costs, therefore, the subject of its effective utilization, has always been of interest. World wide there are about three hundred research reactors. Of these, 92 are located in the developing countries. Together, these reactors represent quite significant research potential. In the present paper, reasons of underutilzation, procedures necessary to measure the productivity, ways and means of enhancing the utilization of research reactors are described. In the end, use of two research reactors at PINSTECH are described to illustrate some of the ways in which a successful utilization of a research reactor can be made in the developing country.

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1. INTRODUCTION

Nuclear science and technology is an important field of knowledge that is playing a significant role in many segments of today's economy. Not only it is worth while subject for investigation, it also has great influence when applied to the fields of energy, utilization of natural resources, and development of high technology. These circumstances constitute a powerful incentive for every country to enter this field, to such an extent that the degree of development of a nation can be assessed according to its progress in nuclear matters.

In developing countries, nuclear science plays an important role and its contributions can take many forms: by perfecting and raising the standards of technical and scientific knowledge; by introducing modern, effective methods in medicine, non destructive testing, use of radiation for varied purposes, production of radioisotopes, and generation of energy. It is easy to see that to achieve this, both human and material resources are required, among which training, research and test reactors, as well as other facilities, are of vital importance.

As the research reactor involves a big capital investment on the part of any institution, therefore, subject of its effective utilization, has always been of interest. In the following paragraphs, some of the important aspects concerning the optimum utilization of a Research Reactor (RR) are briefly discussed.

2. PRODUCTIVITY OF RESEARCH REACTORS

There are some 323 operational research reactors throughout the world (IAEA, 1991) (Fig. 1 - 2). Of these 92 are located in 39 developing countries. These reactors represent significant research potential. Since, the research reactor constitute a major financial commitment, it is important that they be operated in a productive manner. Productivity may be defined as the sum of new knowledge generated, knowledge transferred to others and another definition is this sum expressed as a function of cost incurred. In either case, a consistent measurement is difficult and more qualitative than quantitative.

2.1. CLASSICAL PRODUCTIVITY EVALUATION

In a classical economic evaluation, a close loop exists. Certain operating and capital expenses are incurred in providing a service or manufacturing an item. The service or item is sold for a price that must equal or exceed the cost to remain economically viable. Operating expenses include wages, materials, utilities, maintenance, distribution and corporate overhead. Capital expenses include the depreciation of facilities and equipment. Careful and tedious accounting policies and procedures are required. Income in excess of operating and capital expenses constitute profit. Corporate research is typically funded by profits from ongoing business activities.

2.2 ELEMENTS OF RESEARCH REACTOR EVALUATION

A similar analysis of RR operation shows that no such close-loop model exists for three reasons. First, the input or support for the operation comes from sources related to output in a very indirect manner. Second, the accounting system for expenses is not designed to show economic viability and, therefore, provides inadequate information for such a model. Third, the output is not measured in monetary terms, eliminating a consistent feedback parameter. Input or funding for research reactor includes state funding, research and equipment grants from other sources. Output includes academic instructions (experiments performed by research staff and students), analytical services (measurements or diagnostic performed for researchers), and operational services (work performed with researchers in the development of new techniques or new knowledge).

2.3 MEASUREMENT OF RESEARCH REACTOR PRODUCTIVITY

In an absolute sense, productivity can be measured in terms of research reactor in various categories:

- Total reactor users
- Services and analyses performed for researchers and Industry
- Thesis and publications involving major or minor RR utilization
- Number of students involved
- Experiments or time per student

The data can be obtained from the annual reports of the institutions. It is necessary that definitions must be provided for uniform reporting of each category, which will allow meaningful comparison among research reactor facilities.

Relative productivity, i.e., RR output relative to expanse, requires significant standardization of accounting techniques to provide the most basic qualitative or comparative analysis. The first step for a meaningful comparison is to identify RRs with similar facilities and services. Directory of Nuclear Research Reactors (IAEA, 1989) provides much of this information: type of research reactors, experimental facilities such as neutron irradiation facilities, number of beam tubes, neutron fluxes, annual operational costs, and type of research carried out at each research center. Although, IAEA directory does provide the information about the existing experimental facilities, but it does not give that how many of these facilities are actually being used. For example, the number of beam tubes available at RRs is 5, but except for a few countries, hardly all the facilities are being utilized for experimentation. Of course, this depends upon the available financial and manpower resources, but this does reflect the level of utilization of RR facility.

The second step is to compare various standardized cost components, such as personal expenses, operating supplies and equipment, and major capital improvements. Upon analyzing such comparable data, RR administration can learn from the experiences of others and for ways of enhancing productivity within their own facility. It will also provide funding agencies with an indication of financial commitment of the host institutions and justification for financial support.

2.4 REASONS OF UNDERUTILIZATION

Through out the developing world, the use of research reactors are never utilized upto their full potential. It is quite difficult to pinpoint the single most important factor contributing to the underutilization. However, the major factors are:

- Financial constraints
- Old instruments
- Shortage of trained manpower
- Lack of large user base
- Isolation of scientists
- Buereaucratic difficulties
- Lack of Scientific Environment

Most of the reactors were installed in the middle fifties and early sixties. With the passage of time, the instrumentation installed at these reactors became obsolete. However, due to one reason or other, these instruments were not upgraded with the result that use of these instrument became less efficient and time consuming. Due to the isolation, it is not possible to get new ideas in various fields of research and development relating to the RR utilization and in the absence of proper orientation of R & D activities at the research centers, the already meager trained manpower becomes stagnant. Another point for the under utilization is probably the lack of minimum level of experienced manpower available at the research centers to start a viable research program.

2.5 ENHANCEMENT OF RESEARCH REACTOR UTILIZATION

There are number of ways to enhance the research reactor utilization. First of all, for increased reactor utilization, the choice of the reactor instrumentation has to be implemented which makes optimum use of the available neutron flux, for instance, in case of neutron diffraction, by focusing devices, multidetectors, large samples (if available), and so on. It is obvious that increasing the detector count rate by *Sophistication* at the beam periphery is much cheaper than increasing the reactor power. In particular, instruments should be built which inherently do not need a very high neutron flux, such as instruments which select only one parameter, e.g., momentum, and not both momentum and energy.

Secondly, in order to develop a program for the optimum use of the research reactors, the need of the hour is to develop and implement a dynamic *outreach program* to significantly increase the role of research reactor. The program should be designed to identify and inform a potential users (outside the facility) of their programs can be augmented through the use of reactor facility. The goal of the program should be to use the reactor facility to its optimum potential for educational and research purposes in all disciplines.

The outreach program should consist of a three step process:

- identifying potential users and their needs
- informing potential users of ways their programs could be augmented through reactor usage
- motivating potential users to utilize the facility

As a first step, this can be achieved by establishing a link between the Reactor center and a university in order to obtain thesis and post-graduate research students who will play the most important role to establish a fruitful scientific life at a research facility. This link could be achieved by integrating the reactor facility into a University faculty (e.g. like the reactor FRM in Munchen-Garching). A tremendous group of potential users exists in department outside nuclear engineering. Chemistry, life sciences, geology/geophysics and physics programs can be significantly improved through the judicial use of reactor facility.

A natural product of the outreach program should be an increased research output. There is no better way of reaching out to potential researchers than to integrate the use of a reactor into their curricula. As potential researchers learn of the reactor's capabilities, they will be drawn to use the facility as a matter of convenience. Thus, the end result of continued outreach program will be to significantly increase educational role across the campus in instructional and research support.

In the second step, it is necessary to outreach the local industry. This can be done by arranging seminars and workshops for the local users and by informing them of capabilities and type of services which RR can provide to solve their problems. Recently, in Pakistan, with the help of RCA/IAEA, PINSTECH arranged a seminar on the Application of RR based Nuclear Techniques for the metal and manufacturing industry. Although, the audience was limited, but the consensus of the seminar participants was that this type of activities should be a regular feature. Initially, the services to the users can be provided free of charge, but later on the services can be charged. The funds so generated can be utilized for the upgradation of the existing facilities and establishing the new ones. Similar workshops on the regional level have been found very useful.

Thirdly, it is necessary to initiate collaboration among the developing countries. Some of the developing countries have developed good expertise in one field or the other and also have good experimental facilities available. By initiating collaboration, researchers can get trained at these centers and then can start similar activities at their home institutes.

Finally, it is also important to give RR scientists hands on experience on the modern instruments at the leading research centers. This can be done by arranging short and long term courses for the research reactor users. IAEA is a very appropriate organization which can arrange such sort of activities.

3.0 UTILIZATION OF PINSTECH REACTORS

In Pakistan, the nuclear program was initiated in mid sixties. Pakistan entered the nuclear era by installing a 5MW swimming pool type, The Pakistan Research Reactor(PARR - I) at Pakistan Institute of Nuclear Science and Technology (PINSTECH) in 1965. The main objectives for establishing institute were:

- Provide nuclear education at university level in a broad range of nuclear sciences;
- Promote the formation of an overall nuclear scientific and technical infrastructure for research and development and to support the nuclear power program of the Pakistan Atomic Energy Commission.

The emphasis of course was on the utilization of the research reactor for the studies of Nuclear Physics, Solid state Physics, Activation analysis, for the production of radioisotopes and training of man power. PARR - I has recently been renovated and upgraded to 9MW. PARR - II is a 30kW MNSR which was installed in 1989 at PINSTECH. Some examples of utilization of two research reactors include the following.

3.1 Neutron Beam Research

This is an extremely valuable tool for the determination of structure of materials. Neutron scattering, along with X - ray diffraction and electron microscopy is routinely used for materials characterization. For the neutron diffraction studies a triple axis neutron spectrometer (TAS) was acquired from Poland. The TAS (Fig.3) has 5cm x 5cm beam aperture. Using the soller collimators the collimation at the monochromator and analyzer system can be varied between 10 to 60'. The neutron background using a BF_3 detector is about 2 counts/minute. The monochromated neutron flux at sample position is 10^5 $n/cm^2/sec$ at a wavelength of 1A. Applications include

3.1.2 Structure Determination of Cellulose

The unit cell of cellulose I has been a subject of study for about 50 years using x-ray and electron diffraction techniques. However, there was considerable discrepancy among the lattice constants reported by various authors (Meyer and Misch, 1937; Jones 1958, 1960; Honjo & Watanabe, 1958). Neutron diffraction studies conducted at PINSTECH (Ahmed et al 1976) gave the unit cell for cellulose - I as a = 16.78A, b = 10.3A, c = 15.88 A and $\beta = 82^{o}$ and hence we are able to confirm the results of Hunjo & Watanabe. We were also able to observe the diffraction peaks which were not observed in the X - diffraction pattern (Fig. 4-5). The studies were latter extended to cellulose - II (mercerized cotton).

3.1.3 Order - Disorder Phase Transitions

The order-disorder transition in FeAl alloys was first reported in 1932. Since then, much effort has been put into understanding the order-disorder transformation in different systems particularly in the FeAl system. However there is some disagreement with regard to the type of transition from disordered to FeAl, Fe_3Al ordered phases. Neutron diffraction technique was used to study the order - disorder phase transition in Fe Al alloy for compositions 20.24, 24.15, 28.06, and 31.45 at. % Al (Ahmed et al 1982). We confirmed that the phase transition from the disordered alpha phase to ordered FeAl and from FeAl to Fe_3Al is of continuous nature. The value of critical index beta of the order parameter was found to be 0.302(9). The phase transition in sample with 24.15 at.% Al is shown in Fig.6.

3.1.4 Texture Studies of Copper and Aluminum

At PINSTECH sheets of 99.999% aluminum and 99.99% copper were cold rolled to 92% reduction in thickness for texture studies by neutron diffraction (Beg et al 1985). A piece of copper single crystal was also rolled. The results showed that all samples of f.c.c. metals did not attain standard texture. One of the aluminum samples ended up in [200] (002) texture (Fig.7), whereas the sheet made from copper single crystal followed the orientations of the original crystal. Only the specimens prepared from a billet which was carefully heat treated and mechanically worked gave standard orientations.

3.1.5 Lattice Dynamics of Mixed Alkali Halides

Studies of mixed materials and alloys are very important in the fields of solid state physics and metallurgy. Alkali halides are ionic salts and they are easier to alloy. First detailed lattice dynamical study of mixed alkali halides was carried out at PINSTECH. Acoustic phonon branches, both longitudinal and transverse were measured in a single crystal of $K_{0.5}Rb_{0.5}Cl$ (Aslam et al, 1976). Fig. 8. gives the dispersion relations and the shell model fit for $K_{0.5}Rb_{0.5}Cl$. From the measurements, it was observed that all mixed alkali halides have split or double phonons which disperse together. This is a direct result of mass disorder. It was further deduced that interatomic force constants and effective ionic charges are reduced on mixing and that the mixtures are elastically more anisotropic than the constituent.

3.1.6 Debye - Waller Factors of Materials

We have measured, the Debye-Waller factors of various elements and alkali halide materials. Furthermore concentration dependence of the Debye temperature in mixed alkali halide systems was studied. For these systems, it was observed that concentration dependence of Debye temperature is not linear. The present results also indicated that the values of mean square displacement of atoms obtained using the diffraction data were composed of two factors. One due to the dynamical factor based on lattice vibrations and the other due to the static variation in atomic positions. The static variation would occur due to different sizes of the constituent ions. Knowledge of these factors is important and one has to be careful in evaluating various constants like specific heat, elastic anisotropy, shear and Young's moduli for these materials. Table 1 summarizes the results of these investigations.

3.2 Radioisotope Production

Applications of radioisotope are mainly in the medical field. The radiopharmaceuticals produced are sent to various Nuclear Medical Centers all over the country where they are used primarily for diagnostic purposes and treatment of various diseases. . Apart from the production of radioisotopes for medical applications, PARR - I and PARR - II generates radioisotopes for tracer experiments for applications in industry and hydrology. Fig. 9. and Table 2 gives the year wise production of radioisotopes and radiopharmaceuticals produced at PINSTECH.

3.3 Nuclear Engineering

Many kinds of studies can be undertaken that utilizes the flexibility of a swimming pool reactors. These include flux distribution, thermal - hydraulic studies etc. A principal benefit of these activities is training of personnel and students for other nuclear programs. PARR - I has been regularly used over the years for the training of operators and supervisors as well as for provision of reactor experiments to the M.Sc. (Nuclear Engineering) students of the Center of Nuclear Studies. These students after qualifying the M.Sc. degree are now employed in several projects of Pakistan Atomic Energy Commission. PINSTECH Reactor has thus played a key role in imparting a useful and essential experience to the technical manpower for the development of human resources.

3.4 Nuclear Physics

This work is mainly basic research in the field of neutron capture gamma ray spectroscopy. The gamma ray spectrometer has been designed and is being installed at one end of the through beam tube.

3.5 Neutron Radiography

Neutron radiography is a multi-discipline technique with a wide range of applications in nuclear, aerospace, and other industrial sectors. A neutron radiography facility is being built for testing of various materials and components. It is planned to extend the neutron radiography services to various public sector organizations after the technique is developed.

3.6 Neutron Activation Analysis

PARR - I and PARR - II provides service in research and commercial uses of neutron activation analysis technique. Facilities include high - and low flux irradiation facilities, automatic sample transfer system for short lived activities. A prompt gamma activation analysis system is under fabrication. The Neutron Activation Analysis (NAA) technique has been used for the trace element analysis of geological, biological, environmental and reactor materials.

4.0 ROLE OF IAEA

As has been mentioned earlier, for the optimum utilization of RRs, upgradation of existing instruments is of paramount importance. But for this purpose, funds are needed which the government of member states may not be able to provide. Therefore, it is necessary for IAEA to provide the funding for the upgradation of the instruments.

IAEA is also arranging workshops of three weeks duration on research reactor utilization on yearly basis. The number of workshops should be increased. This will give scientists from the developing countries an opportunity to establish contacts with the scientist at the leading nuclear research centers. This will also enable scientists and researchers to visit the facilities and nature of research program persued by the centers.

IAEA's activities in organizing the seminars/workshops at the national and regional level, is thus helping the member states in the better utilization of research reactors and creating public awareness in this direction.

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TABLE CAPTIONS

Table 1	List of materials for which thermal parameter B has been measured at PINSTECH by the powder neutron diffraction technique.
Table 2	Radioisotope production at PINSTECH.

FIGURE CAPTIONS

Fig.1 Number of Research Reactors in the world.

Fig.2 Operational Research Reactors in the world.

Fig.3 Layout of the triple axis neutron spectrometer TKSN-400 at PINSTECH

Fig.4. Neutron diffraction pattern of Cellulose-I at neutron wavelength of 1.676A

Fig.5 Neutron diffraction pattern of Cellulose-II at neutron wavelength of 1.07A

Fig.6 Temperature dependence of the (111) and (200) superlattice peak intensity in FeAl (24.50% Al)

Fig.7 (111) Pole figure of cold rolled copper sheet

Fig.8 Phonon Dispersion Relations in mixed $K_{.05}Rb_{05}I$

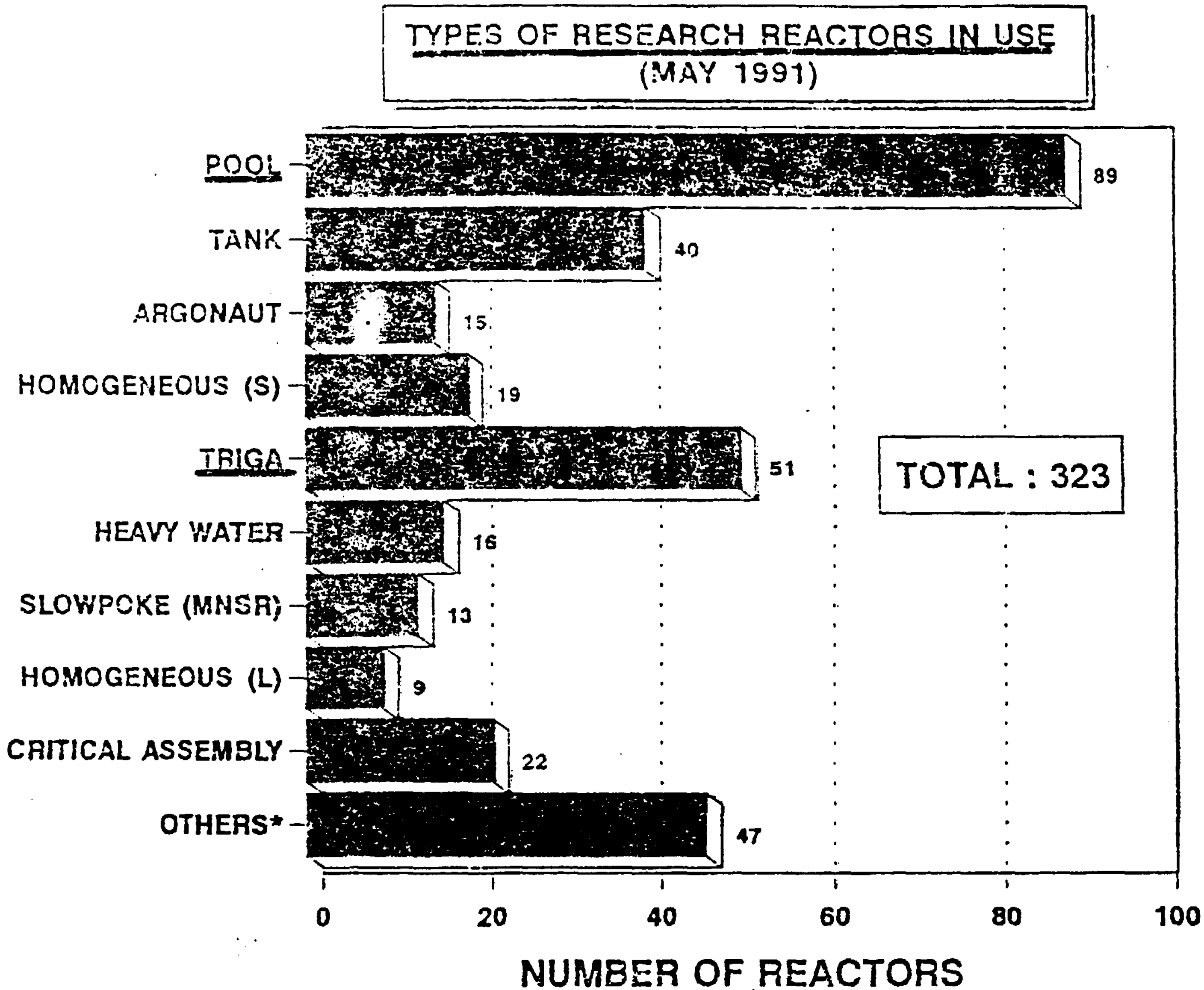
Fig.9 Yearwise production of radioisotopes and radiopharmaceuticals at PINSTECH

Table 1: List of materials for which the thermal parameter B has been measured at PINSTECH by the powder neutron diffraction method

Material	B^+ (A^2)	B^-(A^2)	B (A^2)	Θ(K)	Reference
Mo			0.25(1)	385(7)	Bashir et al (1992)
$K_{0.5}RB_{0.5}Cl$			2.39(12)	172(10)	Bashir et al (1992)
Si			0.45(2)	531(11)	Beisheng et al (1990)
RbCl			2.43(20)	153(7)	Ghazi et al (1989)
Nb			0.55(5)	262(12)	Bashir et al (1987)
KF			1.23(11)	312(14)	Beg et al (1981)
RbF			1.40(25)	216(19)	Beg et al (1981)
$K_{0.5}Rb_{0.5}F$			1.84(20)	214(12)	Beg et al (1981)
TlCl			3.07(22)	97(4)	Mahmood et al (1980)
RbI			3.19(11)	101(2)	Beg et al (1979)
KI			3.06(16)	117(3)	Beg et al (1979)
$K_{0.7}Rb_{0.3}I$			3.10(24)	112(4)	Beg et al (1979)
$K_{0.5}Rb_{0.5}I$			3.52(17)	102(3)	Beg et al (1979)
$K_{0.3}Rb_{0.7}I$			3.14(11)	105(2)	Beg et al (1979)
ZnTe	1.26(5)	0.74(5)	0.91(5)	198(5)	Bashir et al (1988)
UO_2	0.23(7)	0.43(7)	0.25(9)	396(70)	Ahmed et al (1979)
KBr	2.55(7)	2.20(4)	2.33(30)	158(4)	Butt et al (1976)

Table 2: RADIOISOTOPE PRODUCTION AT PINSTECH

RADIOISOTOPE	CHEMICAL FORM (SOLUTION)	PRODUCTION/BATCH
Iodine-131	NaI	(10 Ci)
Iodine-131	Hippuran	(20 mCi)
Technetium-99m	Chromatographic Generator, elution as pertenchetate	(1 Ci)
Phosphorus-32	Na_3PO_4	15 mCi)
phosphorus-32	Na_3PO_4	(10 Ci)
Sulphur-35	H_2SO_4	(10 Ci)
Gold-198	Colloidal	(3 Ci)
Chromium-51	Sodium Chromate	(400 mCi)
Chromium-51	Chromic Chloride	(400 mCi)
Chromium-51	EDTA Complex	(400 mCi)
Chromium-51 with carrier	Potassium Chromate	(2 Ci)
Sodium-24	Sodium Chloride	(10 mCi)
Bromine-82	Sodium Bromide	(5 mCi)
Iron-59	Ferric Chloride	(3 mCi)
Hg-197&203 Sb-125, Cd-115m Tc-99m, Cs-134	Various Chemical Forms	Different Quantities



* PWR-LMFBR-PRESSURIZED-ZERO POWER
SODIUM FAST-SODIUM COOLED

Fig.1 Number of Research Reactors in the world.

POOR QUALITY ORIGINAL

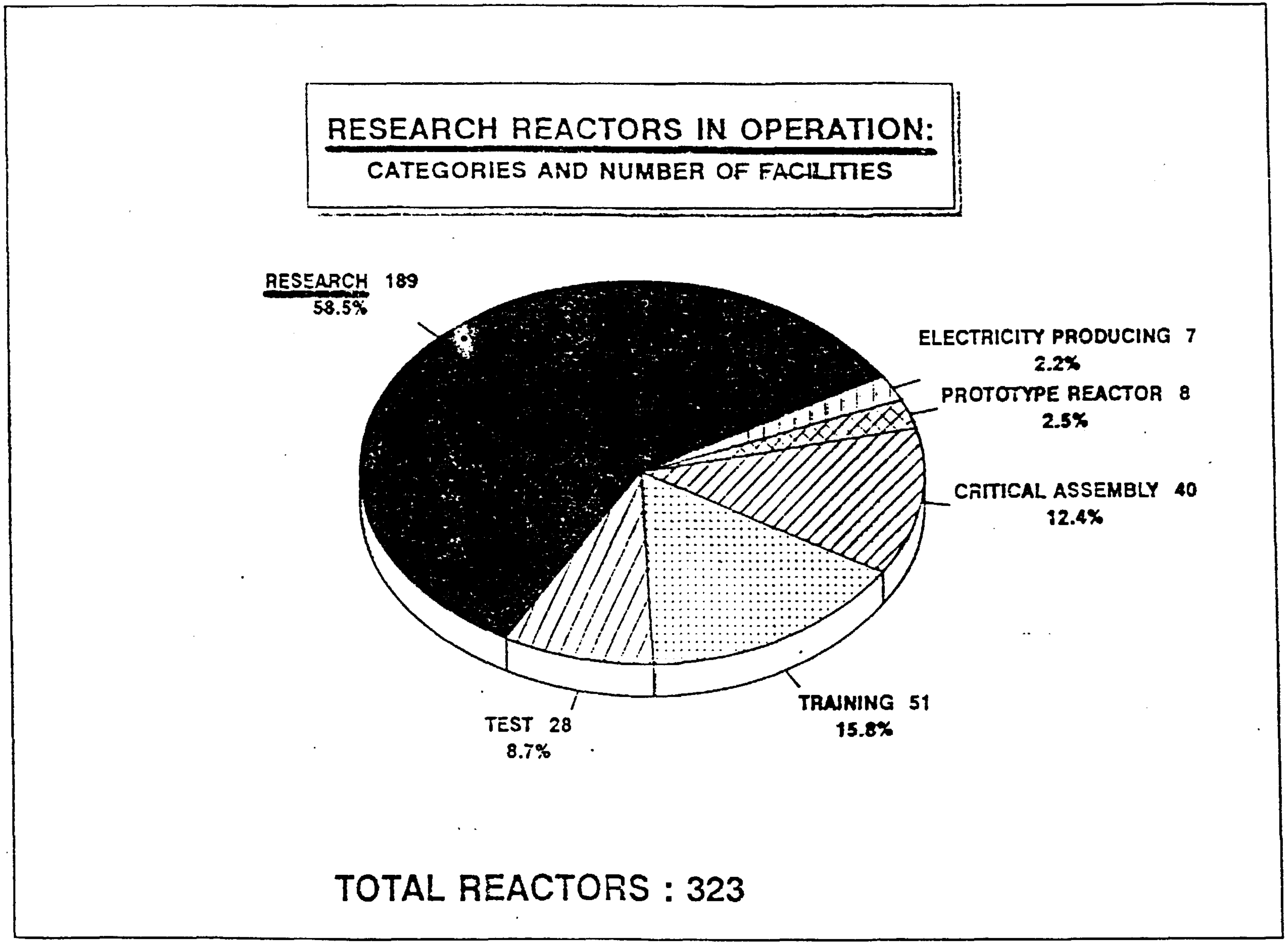


Fig.2 Operational Research Reactors in the world.

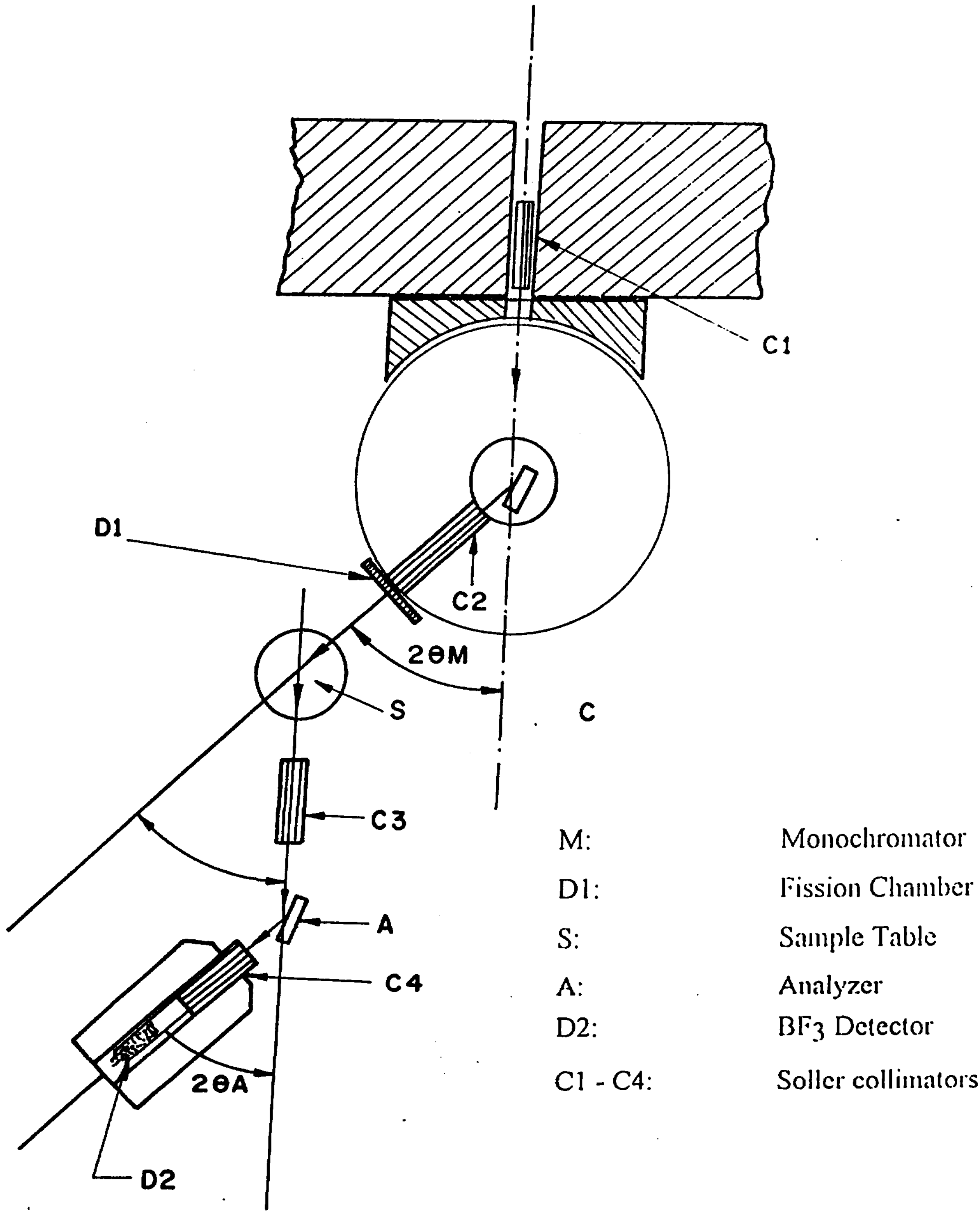


Fig. 3 Layout of the Triple-axis Neutron Spectrometer TKSN-400 at PARR-I.

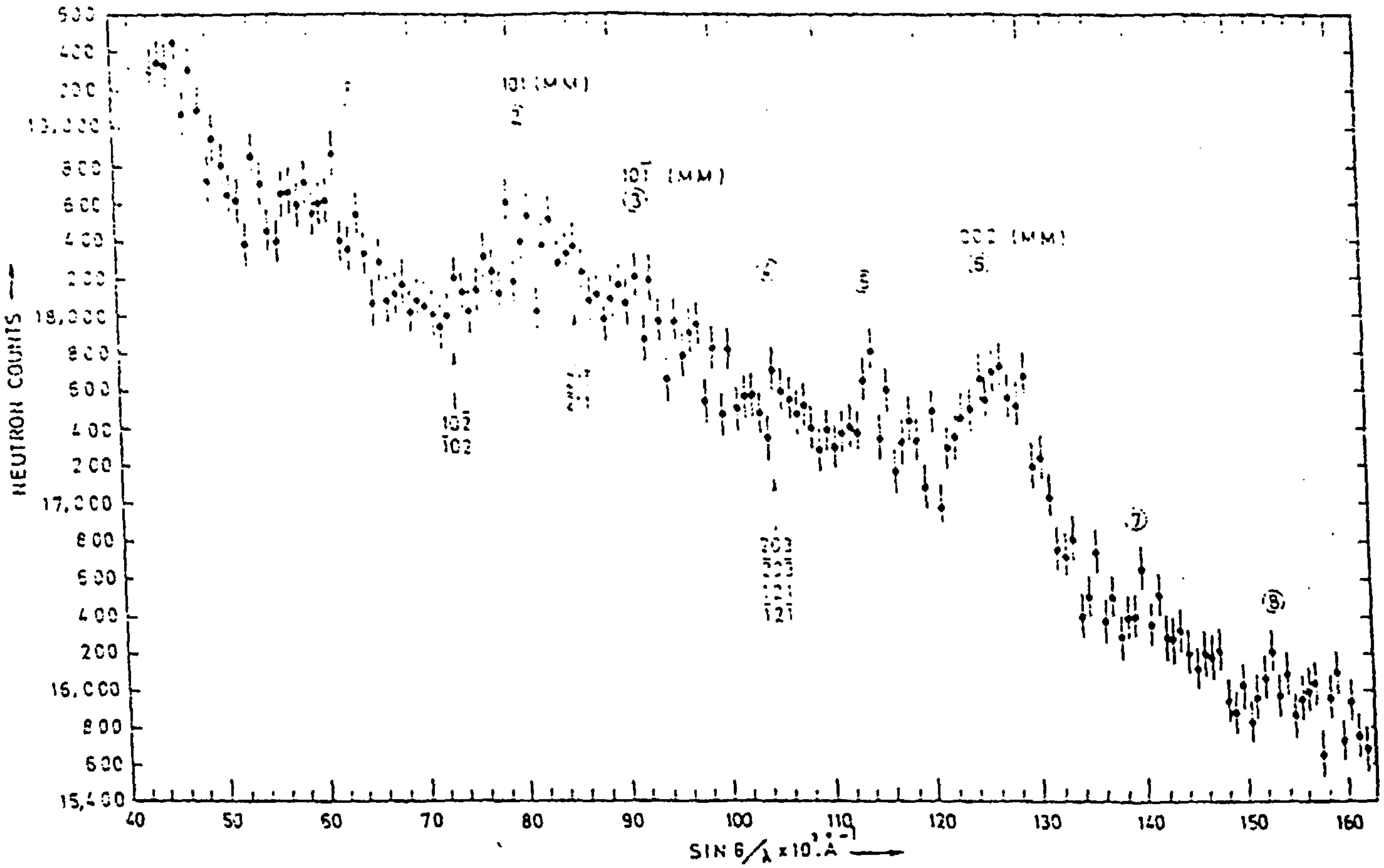


Fig. 4 Neutron diffrction pattern of cellulose - I (cotton crystallites) at neutron wave length of 1.676 Å.

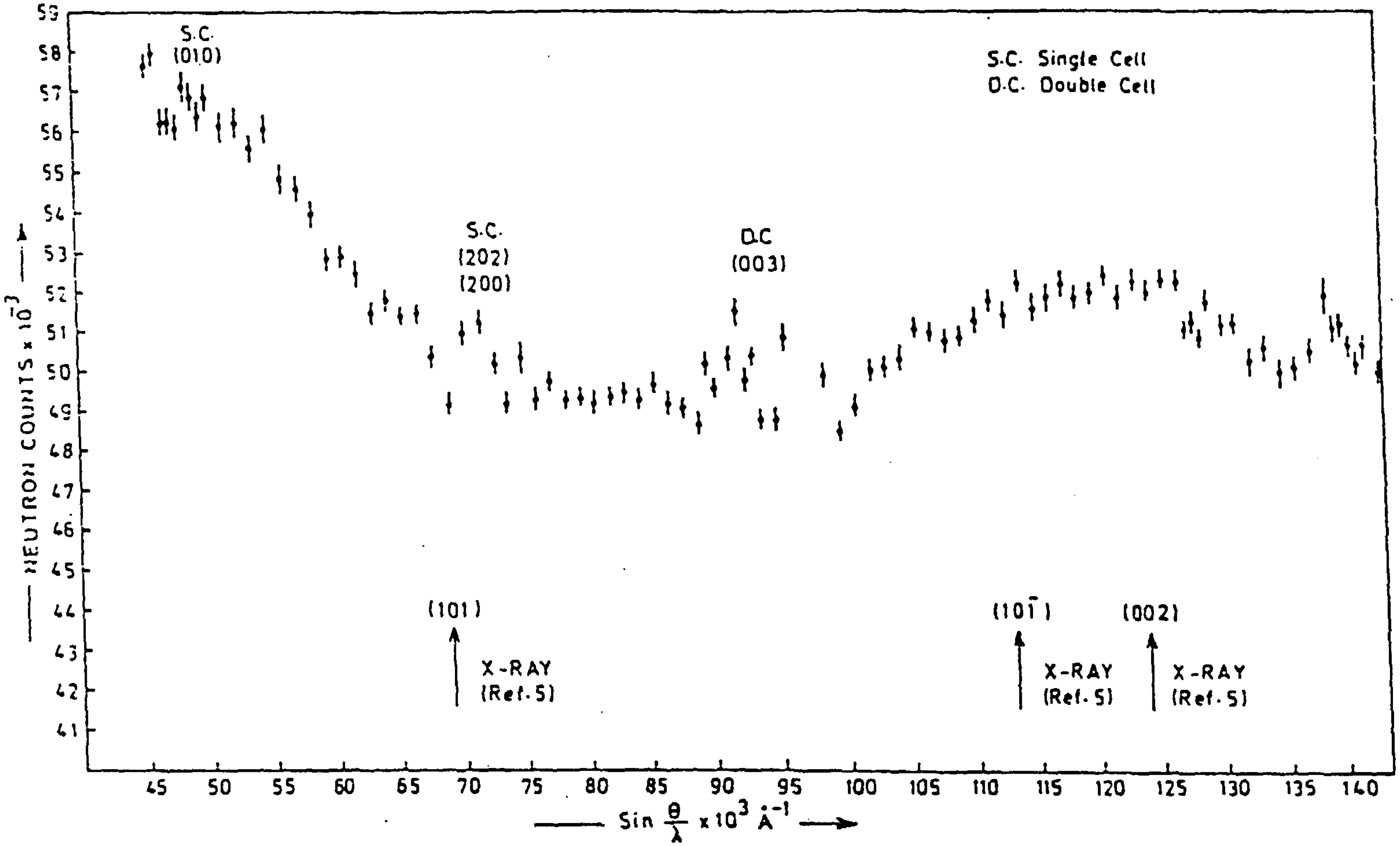


Fig. 5 Neutron diffraction pattern of cellulose II (mercerized cotton) at neutron wavelength of 1.07 Å.

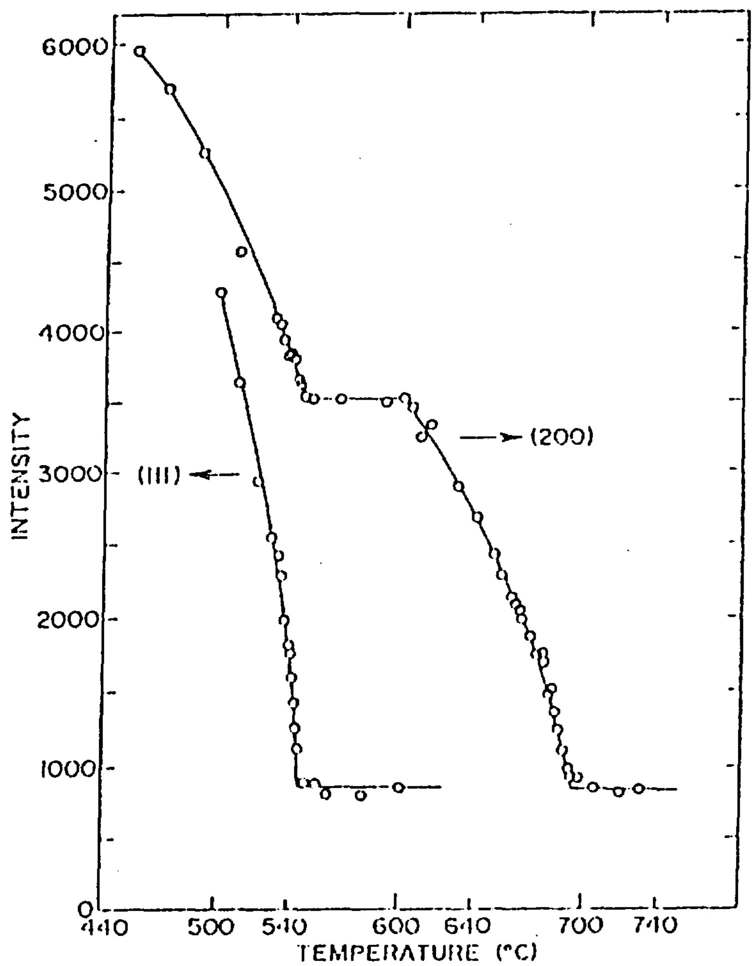


Fig. 6 Temperature dependence of the (111) and (200) superlattice peak intensity in Fe-Al (24.50% Al).

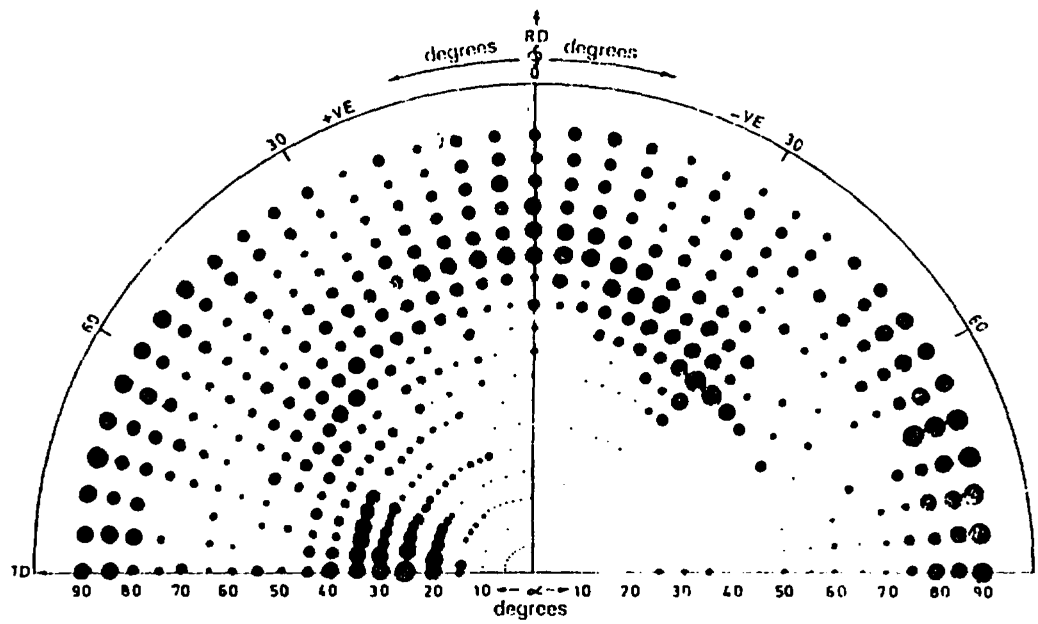


Fig.7. (111) pole figure of cold-rolled copper sheet (sample 11, 94% reduction).

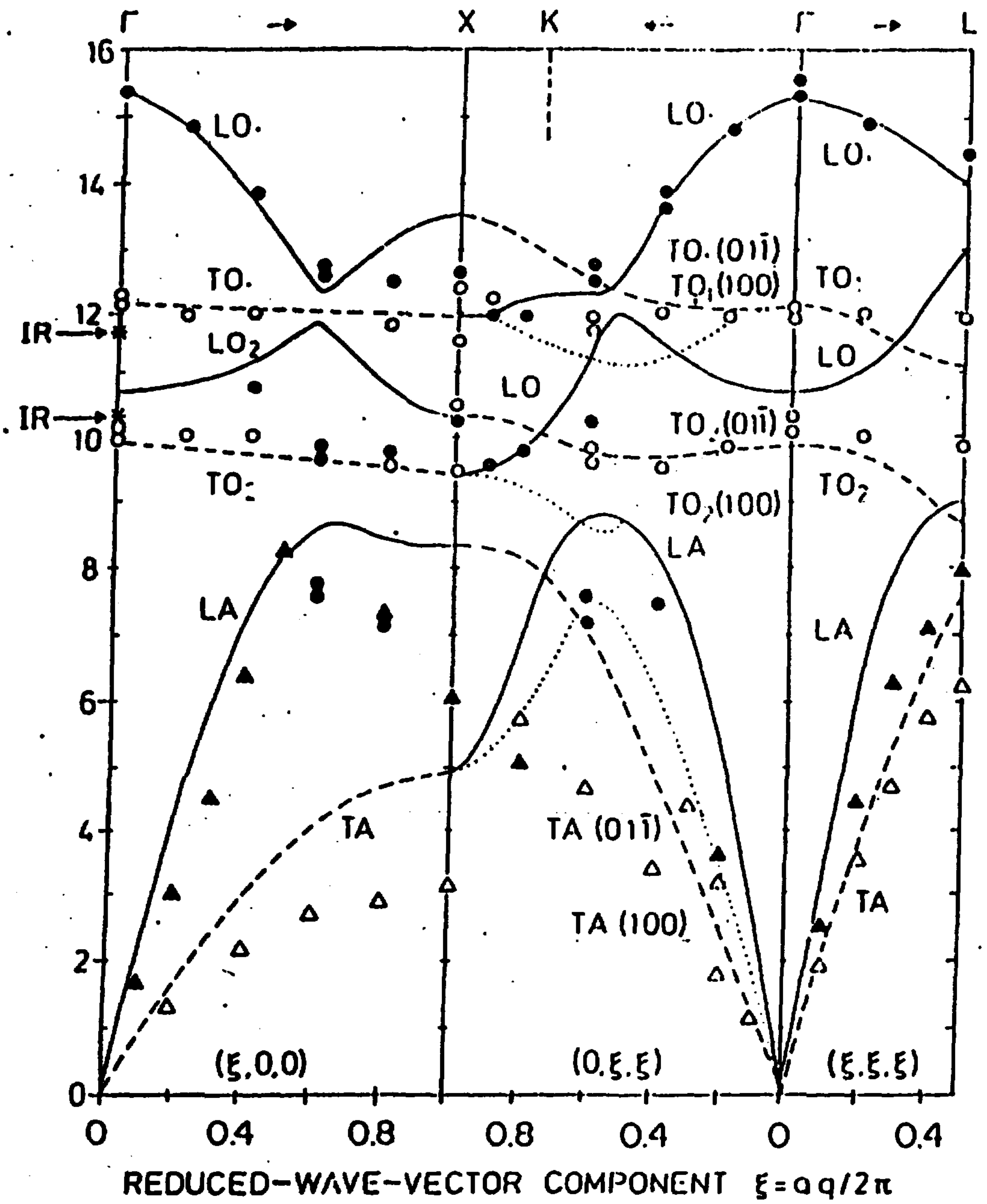


FIG. 8. Phonon branches calculated by the pseudo-unit-cell model. The model parameters are deduced from the elastic constants, the LO/TO Γ-point frequencies and the high- and low-frequency dielectric constants.

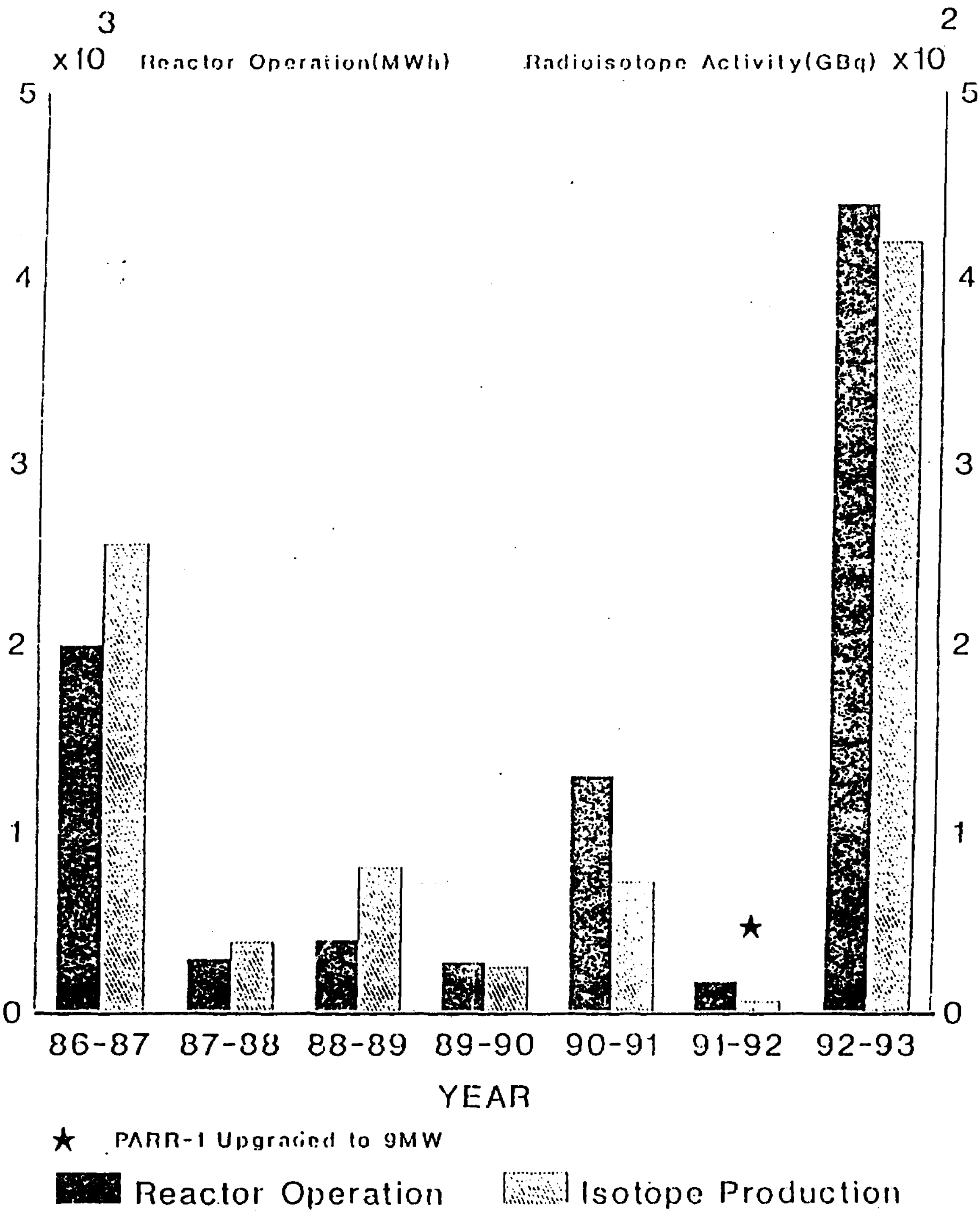


Fig. 9 Production of Radioisotopes and Radiopharmaceuticals