on PTF cells.
2. National Physical Laboratory—single crystal and amorphous silicon solar cells.
3. Jadavpur University—PTF cells.
5. Poona University—a-Si materials.
6. National Chemical Laboratory—a-Si materials.
7. Solar Energy Centre—calibration and reliability test facilities.

A large number of Indians are working in USA on different types of SPV technologies and some of them are in industries holding high positions.

What should be done?

There is no concentrated effort to develop SPV technology in India. It is necessary to set up an Institute for Photovoltaic Science and Technology. Some steps in this direction had been initiated by MNES a few years ago but further action in this regard has not been taken. MNES has formulated very recently new guidelines for R & D activities in the area of renewable energy including SPV. Joint funding of R & D-linked to industry will be preferred although new technologies may have direct funding.

Conclusions

1. In view of the potential of SPV industry in India major investments are needed. Scientists working in the area of condensed matter science may play a key role in improving SPV module technology.
2. With proper investments, planning and execution India should be a leader in SPV technology and should be able to export technology and products.

Condensed matter science and the Department of Atomic Energy

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The present article describes the role of condensed matter science and technology in the development of atomic energy programme as also the role of atomic and nuclear radiations in the study of condensed matter science. It is emphasized that an integrated development of radiation sources, materials and instruments is essential for the healthy growth of condensed matter science.

Radiation and condensed matter

I consider it an honour to have been asked to speak on this special occasion on behalf of my Institution in a Department which has made major contribution to Physics research in India. The subject which I have been asked to touch upon is 'Condensed Matter Science and the Department of Atomic Energy'. In this short presentation I shall not be able to do justice to this very broad title if I talk about specific details. I have therefore chosen to make some general remarks – use broad brush strokes rather than fine brush of a miniaturist.

When it comes to talking about condensed matter science, or science of any kind for that matter, it is possible to take different approaches depending on one's taste. In a lecture de Solla Price, a science historian from Yale has argued that technology gives rise to instruments which are the true drivers of science (Figure 1). Taking a cue from this Rustum Roy, a materials scientist of Pennsylvania has argued that materials technology gives rise to new materials which in turn give rise to new science (Figure 2). Scanning tunnelling microscopy (STM) is an example of the first type whereas purification of Ge and Si may be cited as an example in favour of Roy's case. On the other hand, it has often been said that it is science which pushes the growth of materials as well as technologies. Quantum structures, experiments with which have been labelled as 'playing with quantum mechanics in the laboratory' by Esaki, are examples of this category.

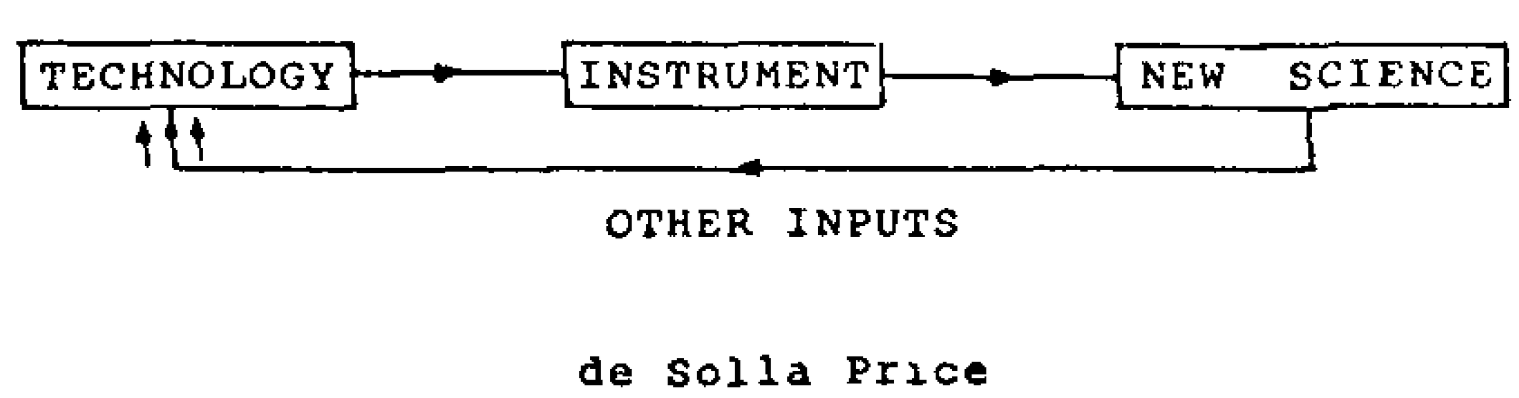

Figure 1. A science historian, de Solla Prices' view of development of science.

These are all partial views which help to project a certain aspect with great force at the cost of others. This happens because one chooses to start this justification at an arbitrary point in an endless chain of events. To take a somewhat more global view, I shall start at the beginning, that is, with the big-bang when there was lot of radiation and little matter (Figure 3). Out of this was born, inanimate matter. With further radiation processing inanimate matter changed to bio-matter. Radiation processing was the primordial mode of materials' processing. Biomaterial gradually evolved into higher species, including man. Many of them were provided with 'instruments' for observation in the form of sensory organs. In the case of homo sapiens, their intellectual needs gave rise to science whereas théir physical requirements gave rise to technology. In early man art, science and technology coexisted. Growth of these activities into larger and larger bodies of knowledge led to specialization and created a distance between science and technology. However, their essential interdependence continues to this day and it is therefore not surprising that in order to reap the benefits of this interdependence teams of multidisciplinary specialists are put together whenever major goals have to be achieved. Growth of science and technology gave rise to new radiations, thus completing the cycle. New radiations, new materials and new instruments each one became the driving force for newer science and newer technology (Figure 3) with physicists (P), chemists (C), materials technologists (M), life-scientists (L) and engineers (E) contributing to the growth cycle in their own ways.

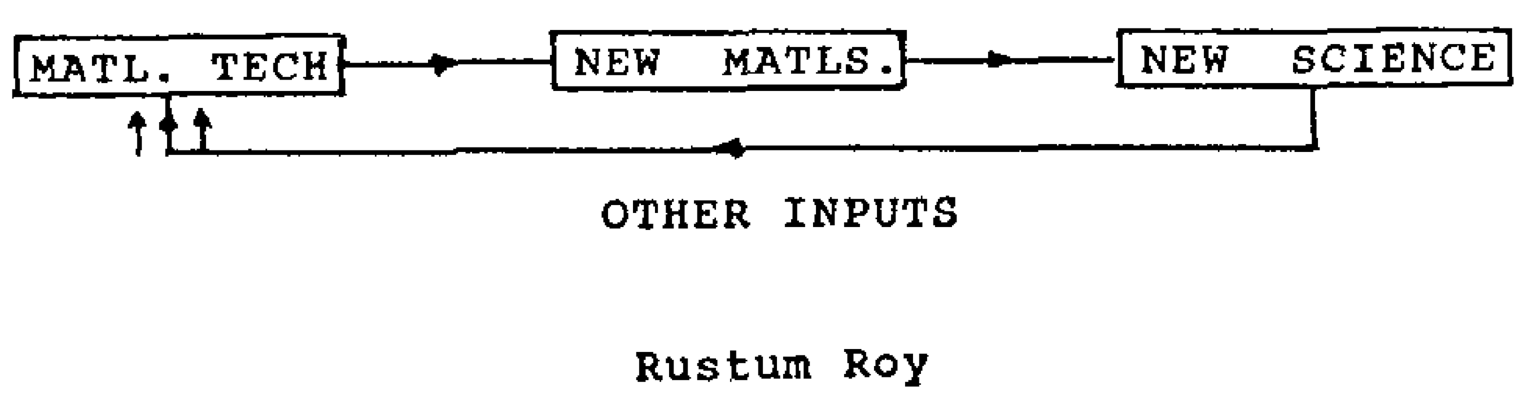

Figure 2. A materials' scientist, Rustom Roy's view of development of science.

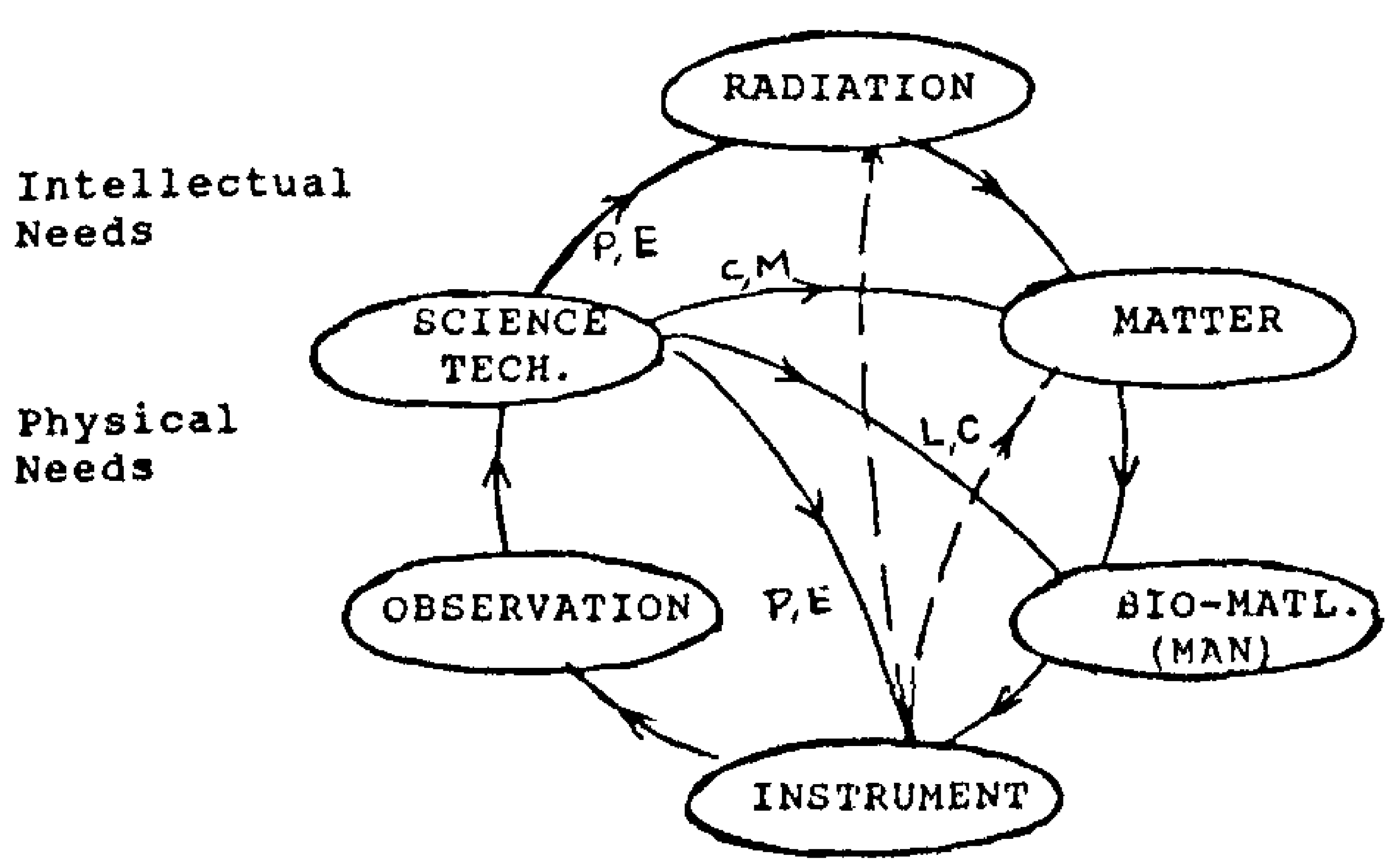

Figure 3. A view depicting interdependence of radiation, matter, science and technology and the role of different disciplines and of instruments.

I would like to discuss the role of DAE in condensed matter science in this general framework. I have already noted that radiation is an important component of this total picture and DAE, as you all know, is concerned a great deal with all kinds of radiations namely, nucleons, ions, electrons and positrons, photons, etc. I shall consider neutrons in some detail and mention the rest only marginally.

Neutron

Condensed matter for neutrons

The bread-and-butter radiation of DAE is the neutron. Discovery of neutrons in 1932 by Chadwick (see Figure 4) led to intense activity in understanding neutron–matter interaction which culminated in the discovery of fission and possibility of chain-reaction. The subject of reactor

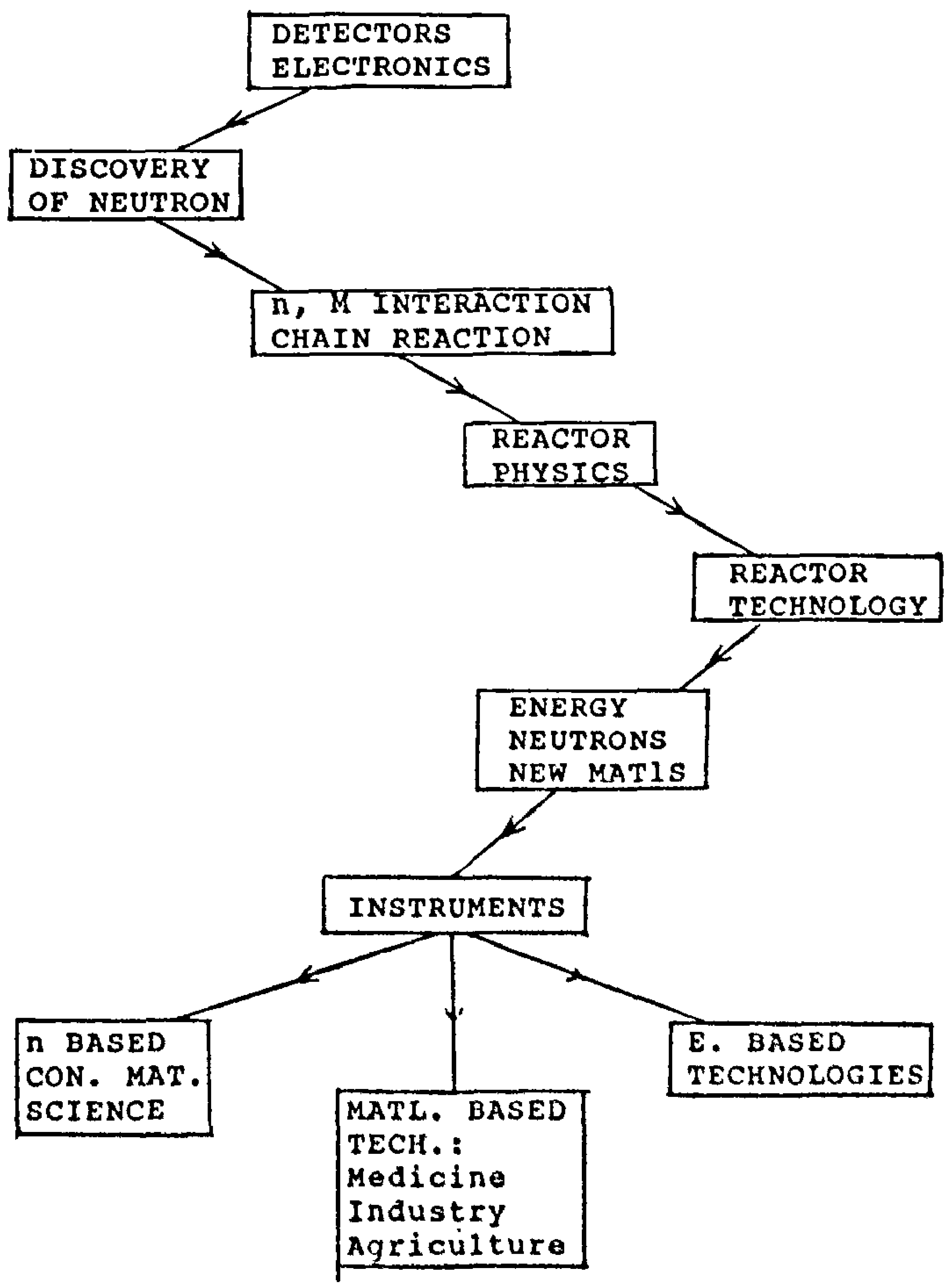

Figure 4. An example in the field of atomic energy to illustrate the interdependence shown in Figure 3.

physics was thus born. Since enormous amounts of thermal energy and thence electrical energy can be so produced, reactor technology emerged as an important techno-commercial activity. This required production of the right kind of fuel (uranium, plutonium, etc.) either as metal or compound, with proper metallurgical microstructure and acceptable thermomechanical properties. To maintain chain reaction moderators of fast neutron like D_2O, Be, etc. were required. Further, fuel had to be contained in containers which have the right neutronic and engineering properties: Zr and zirconium-based alloys play their role here. Thus, there was a need to develop specific materials for reactor technology. As already mentioned, producing these materials requires understanding their macro and microstructural properties in depth on one hand and development of processing methods (flow-sheet) for large scale production, on the other. Table 1 gives a partial list of materials developed for use in DAE. Detailed studies have included various types of phase transformations (Martensitic on pressure tube materials, displacive omega on Ti and Zr alloys, order-disorder on Ni-based alloys, precipitation in inconel, alloy 625, zircalloy, etc.). It is interesting to note that in this pursuit we have now reached a stage where it is possible to do first principles calculation of structures of alloys. With continuously developing programme of DAE such activities will continue to be undertaken in future.

Neutrons for condensed matter

I have hitherto described how condensed matter science and technology served as an input to the reactor technology programme of DAE. Let me now describe how nuclear reactors contribute to the growth of materials and condensed matter science.

There are two aspects of condensed matter science, which are inter-related. One is 'processing' of materials and the other is 'understanding' the processed materials.

The role of radiation processing has had somewhat limited appreciation till now partly because of specialized nature of the subject. In the case of neutron the term processing may be related to production of isotopic materials for medical uses and industrial radiography sources, production of Si with highly uniform doping of P, etc. It may not be out of place to note here that every year about a million patients are diagnosed or treated using a variety of radioactive materials in India.

When it comes to understanding the properties of materials in a nanometric scale in a time regime of nano (10^{-9}) to pico (10^{-12}) seconds, neutron beams again play a very important role. In several areas of science relating to magnetism, atomic dynamics, light atom crystallography, large molecule structure studies etc. neutron continues to be the method of choice. There are many important contributions made by the Trombay group over the years; some of them are listed in Table 2.

Scientists at Trombay have developed the complete range of specialized instruments needed for such studies. Since the present seminar concerns also with plan of action for future it is worthwhile reiterating here that since the programme at BARC is entirely based on indigenous development of instruments for neutron scattering it has been possible to mount a large programme. It would have been impossible to do the same with commercial instruments which are either too expensive or not available as standard items. This also assures that the down time of instruments is reduced to a minimum. Further, most importantly, it provides our scientists a chance to do many novel experiments which would not be possible with commercial instruments. A simple example of this is the world's best measurement of the width of Bragg cut-off in Be, this measurement being a necessary input for the design of a novel high

Table 1. Materials for nuclear applications (flow sheets developed, scaled up for production)

Fuel materials	U, Pu, mixed U–Pu, Th (metal, alloys, oxide, carbide, nitride, silicide)
Moderators	D_2O, Be, Be alloys
Absorbers	B, B_4C, Hf
Structurals	Zr, Zr-alloys (zircalloy2, Zr–Nb, Zr–Nb–Ca, Zr–Nb–Zn) D9 SS
Waste storage	Glass

Besides these several other materials like Ti, V, Nb, Mo, Sn, Ta, W, electronic materials like Ga, As, In, Cd, etc., detector materials like alkali halide crystals and superconductors like Nb-Ti wires have also been developed.

Table 2. Some highlights of neutron scattering results from BARC

First observation of anharmonicity in rotational potential of NH_4^+
Kohn anomalies in Zn
Use of filter detector spectrometer for measuring steep phonon dispersion curves and high frequencies up to 20 THz
Proof of non-local pseudopotential in Be
First observation of Yafet–Kittel (canted spin) ordering in ferrites
Transfer of moments to oxygen ligands in Fe_3O_4
Structure of several amino acids
Rotational correlation functions in CH_4, CD_4
Reorientation dynamics of tetrahedral molecules
High resolution measurement of Bragg cut-off in Be
Interferometry
Small angle diffraction study of intermicellar potential in ionic, non-ionic and mixed micelles
Real-time diffraction of loading of D in Pd.
Extensive structure studies of high T_c superconductors
Coexistence of large range longitudinal spin order with transverse disorder in ferrites

resolution energy analyser system which was designed and fabricated by BARC for installation at the ISIS pulsed neutron source at Rutherford Appleton Laboratory, UK (ISIS is the most intense pulsed neutron source todate).

With the availability of Dhruva reactor and a suite of instruments to go with it, the time was ripe for making this world class facility available to a large community of scientists. Dhruva was made a national facility and made available to university scientists through the Inter-University Consortium for DAE Facilities (IUC-DAEF). About thirty different collaborative condensed matter projects are now underway with different universities (Variable Energy Cyclotron at Calcutta and future synchrotron sources at Indore are also included under this scheme).

Other radiations and condensed matter

While I gave a somewhat detailed account of neutrons as an illustrative example, similar development strategy has been followed in relation to other radiations. Table 3 describes some of the radiation beams either presently available or going to be available in the near future for condensed matter research in DAE units. The table also lists some of the applications in condensed matter science and technology to which these radiations are put in DAE. It is impossible to be exhaustive; only a subset of a variety of studies is listed.

Table 3. Particle beams in DAE

Neutrons	BARC	Magnetism, dynamics, large structures, surfaces
Electrons	CAT BARC	Rad. Damage, materials processing, structure
Ions	BARC VECC, IOP IGCAR, TIFR	Rad. damage, surface modifications, clusters
Positron	IGCAR	Defect sol st, materials processing
Plasma	CAT BARC	Materials processing, laser interaction
Photons (IR, light, VUV, X-ray, γ) (Indus I & II, laser, isotopes)	CAT BARC	Ionic and electronic structure, real time studies (kinetics), dynamics, material processing

Computers

DAE has from the beginning been subjected to controls from some developed countries as far as the sale of computers is concerned. Under the circumstances it became necessary to develop computational hardware as well are software within the Department. This development has served the cause of condensed matter science well within DAE. Groups dealing with varied computational problems (electronic structure, Monte Carlo methods, molecular dynamics, etc.) already exist and one expects that this will be an important component of condensed matter science, indeed all science, in coming decades.

Summary

I have tried to highlight the fact that radiations are an essential part of condensed matter processing as well as nanometric studies.

In some areas, use of radiations is unique in achieving the desired results in condensed matter research.

The coming decade would witness commissioning of additional radiation sources and development of instruments to use these sources.

Basic understanding of some long-standing problems would emerge through use of computers and DAE would continue to make its contribution in this development.

Greater interaction will occur with universities through IUC-DAEF and other such arrangements.

To establish experimental sciences on a firm footing it is necessary to inculcate the culture of indigenous development of scientific instruments. The present chairman of DAE has often stated that the instruments used in front line investigations are invariably developed and found in the best laboratories and 'commercial' instruments are often 'outdated' for these.

DAE would continue with a multipronged approach with balanced weightage towards development of radiations, materials and instruments and hence condensed matter science and technology.

Experience with various programmes of DAE has shown that self-reliance is not an expediency and that it is important as a long term strategy for development of science.