



# Sustained Performance of 8 MeV Microtron at Mangalore University

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## Microtron at Mangalore University

- Designed, developed and fabricated at RRCAT Indore
- Set up in Mangalore University to strengthen the teaching and research programs in the areas of Radiation Physics and allied sciences
- The first of its kind indigenously developed electron accelerator in the country is capable of delivering electrons of energy 8 MeV, intense bremsstrahlung photons of peak energy 8 MeV and also neutrons of reasonably high flux for variety of applications.
- A brief description of this unique facility and the research programs with some sample results are presented





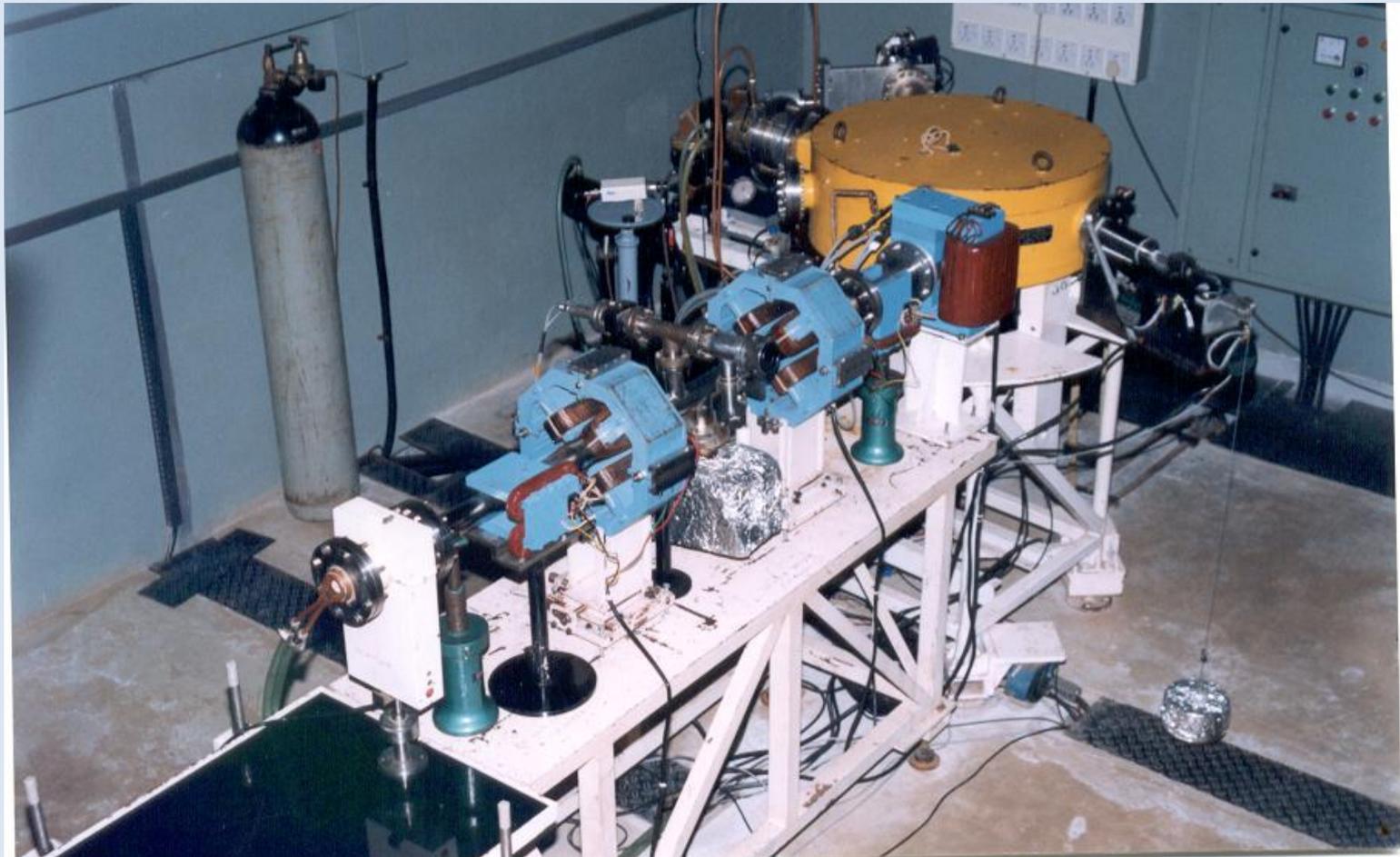
## MICROTRON BEAM PARAMETERS

Electron Energy	:	8 MeV
Electron Beam Current	:	50 mA (max)
No. of Electron Orbits	:	14
Pulse Repetition Rate	:	250 Hz (max)
Pulse Width	:	2.5 $\mu$ s (max)
Beam Size	:	3 mm X 5 mm
Microwave Source	:	Magnetron
Magnetron Power	:	2 MW
Operation Frequency	:	2998 MHz
Dose rate at 30 cm	:	2 kGy/min (max)





## 8 MeV MICROTRON at Mangalore University



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## LABORATORY INFRASTRUCTURE

- Deep Level Transient Spectrometry (DLTS) system for defect characterization in semiconductor devices
- Keithley I-V measurement set with trigger controller unit for electrical characteristics of the semiconductor devices with 2 or 3 terminals
- A UV-Vis Spectrophotometer (Secomam)
- TLD Reader for analysing glow curves of various irradiated TL materials
- Fission chamber and SSNTD facility
- Research Microscope with relevant softwares and imaging accessories
- Laminar flow & Bacteriological grade Incubator
- Ag wrapped GM tubes for Neutron detection
- 41.2% relative efficiency HpGe Detector
- 30% relative efficiency HpGe Detector
- 3" X 3" Flat and 5" x 5" well type NaI(Tl) Spectrometers
- High sensitive ionisation chamber based radiation survey meters (Victoreen & Ludlum) with range of 1  $\mu$ R/h to a few R/h
- DSC/TGA Unit (up to 1500 C)
- Impedance Analyser (20Hz to 120 MHz)





## Research Programs

- **Radiation Dosimetry Studies**  
Chemical Dosimeters - Fricke, FBX, Alanine & Glutamine  
TL dosimeter - CaSO<sub>4</sub>:Dy, Clinical Dosimetry Comparison / Calibration Studies
- **Semiconductor Irradiation Studies**  
Power Diodes, Schottky diodes, Transistors, MOSFETs, Solar Cells etc.
- **Photofission Studies**  
Cross-section, Angular Distribution of fission fragments
- **Radiation Biophysics**  
Chromosome Aberration, Micronucleus Induction in human blood lymphocytes, Cell Survival and Gene Conversion, Relative Biological Effectiveness
- **Radiation Processing**  
Coffee seed, Onion, Potato, Spices, Seeds of non-conventional legumes – *canavalia*, Mucuna Pruriens seeds, Vanilla beans, Bakery items, ayurvedic & siddha medicines, etc.
- **Irradiation studies** on Polymer, Hydrogel, Thin films, Nano particles, Ferroelectric materials, Crystals – NLO, TGS and other organic crystals, etc.
- **Photon & Neutron based studies - Activation Experiments**





## Semiconductor Irradiation Studies

Semiconductor devices are exposed to various types of radiations when they are used in space / radiation environment.

Devices such as power diodes, transistors, thyristors, solar cells, photo-detectors, etc., need to be tested for radiation hardness to determine their tolerance and suitability to different applications

It is not only important to have broader understanding of the damage process leading to various modifications, but is essential to assess the device performance when it needs to be operated in radiation environment

A clear understanding of the degradation mechanism of devices are necessary to improve the device performance against radiation by discovering the ways for minimizing the effects.





## Semiconductor Irradiation Studies

Irradiation of fast recovery semiconductor diode (fast recovery type - 2800V, 710 A, 8  $\mu$ s - fabricated using float zone silicon wafer as the starting material) developed for use in high power applications was carried out (in collaboration with BHEL Bangalore).

Energy levels introduced deep into the forbidden energy gap – Act as traps - expedite the rate of recombination.

Higher the recombination rate of electron hole pairs, faster is the switching.

Forward voltage drop increased but within the limits.

Considerably lower reverse leakage current - An empirical relationship was established for the selection of appropriate dose

Alternate process - gold diffusion –was also conducted.

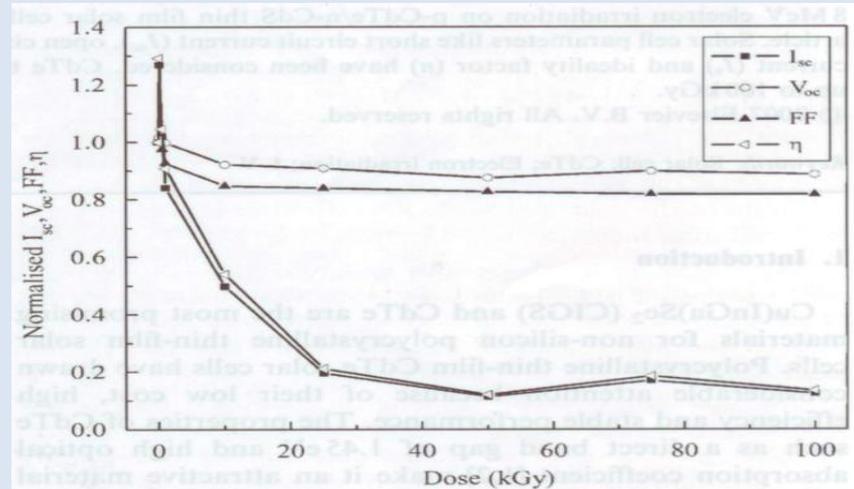
Results are compared – to control the minority carrier lifetime required to tune the switching responses of the diode (desired value  $\sim$  8  $\mu$ s)





## Solar Cell in Radiation Environment

- p-CdTe/n-CdS thin film solar cells - exposed to electrons and characterised in dark and illumination conditions in order to test the device stability in radiation environment
- Solar cell parameters like short circuit current, open circuit voltage, fill factor, conversion efficiency, saturation current and ideality factor were checked
- Study reveals that the thin film solar cells exhibit good stability against electron dose up to 100 kGy.



Normalised solar cell parameter as a function of dose





## Solar Cell in Radiation Environment

- A large decrease in the values of  $I_{sc}$  and  $\eta$  was observed with slight decrease in  $V_{oc}$  and FF

Manly due to generation of recombination centers, which decreases the minority carrier diffusion length.

- The decrease of  $I_{sc}$  and conversion efficiency  $\eta$  – due to darkening of glass substrate upon irradiation (rather than degradation)

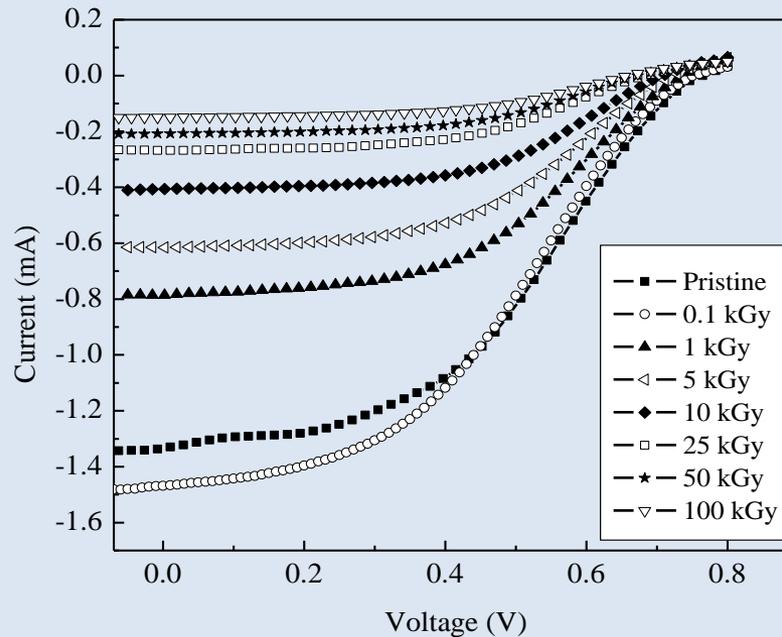
Ionisation followed by creation of color centers is the reason for darkening of glass - space quality glass which remain transparent even after electron irradiation need to be used.





## Solar Cell in Radiation Environment

Different varieties of solar cells with different conversion efficiencies were used for the study. Electrical characterizations at different air mass ratio conditions were studied extensively in collaboration with UNAM Mexico and NREL, USA.



Illuminated I-V characteristics of CdTe/CdS solar cell at various doses of 8 MeV electrons





## Solar Cell in Radiation Environment

- Effect of 8 MeV electrons on Silicon Photo detector fabricated by diffusion of phosphorous into the p-type mono-crystalline silicon wafers of <100> orientation, was also studied.

Device performance degrades with increasing electron dose.

An analysis of I-V and C-V characteristics in dark and spectral response, as a function of dose shows that irradiation introduces recombination centers in the base region of the device this in turn cause degradation of the photodetector performance due to the decrease of the minority carrier diffusion length.

## Radiation Effects on Schottky diodes

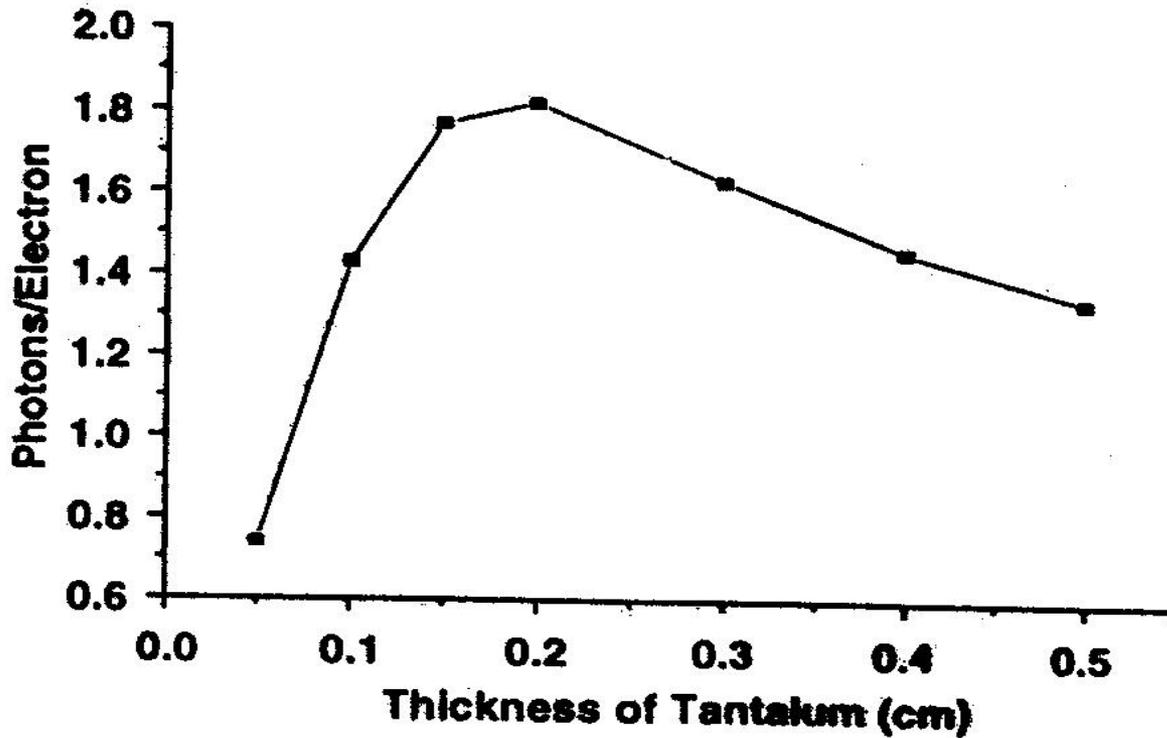
- Irradiation studies on p-Si and SS/CdTe/Au Schottky diodes - reduction in forward current with increasing dose

The degradation in the diode properties mainly due to the introduction of radiation induced interfacial defects via displacement damage (metal – semiconductor interface – through the change in carrier concentration, minority carrier lifetime and carrier mobility).





## Theoretical approach -Bremsstrahlung from Tantalum

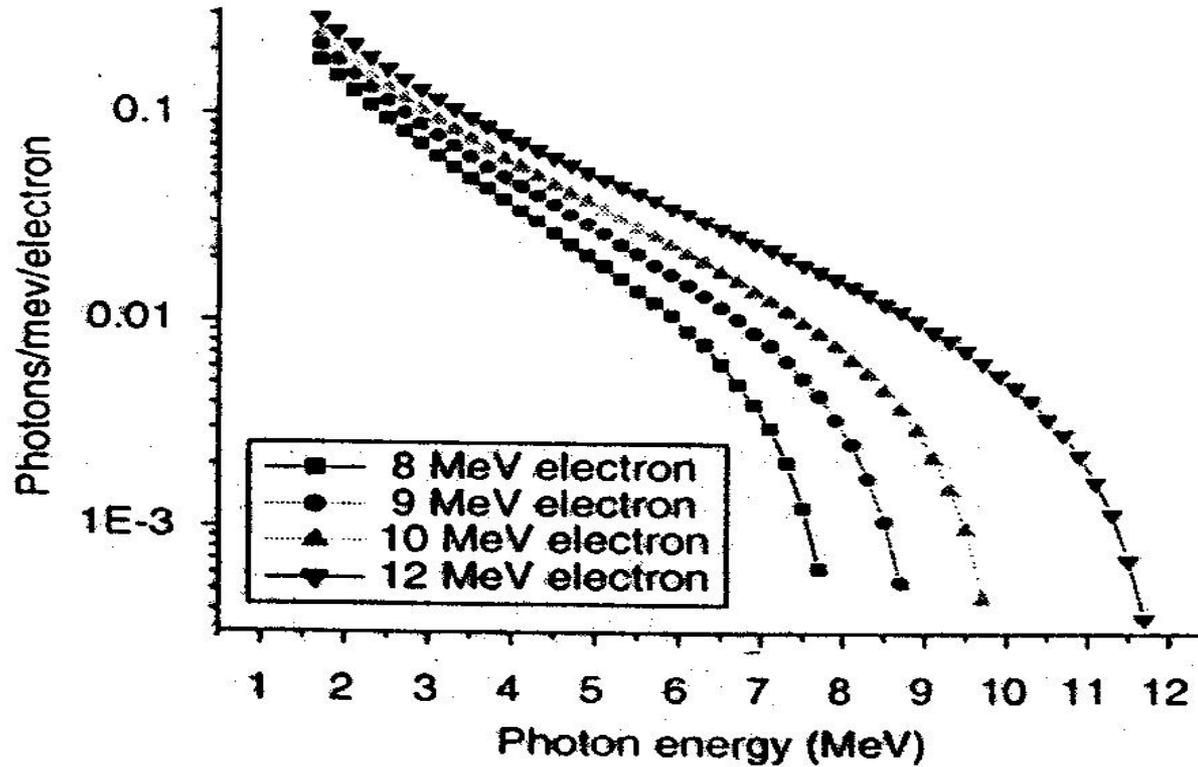


Bremsstrahlung yield for different thicknesses of tantalum for 10 MeV incident electrons.





## Bremsstrahlung Spectrum



Bremsstrahlung spectrum for Ta target for electrons of different energy.





# Photofission Studies

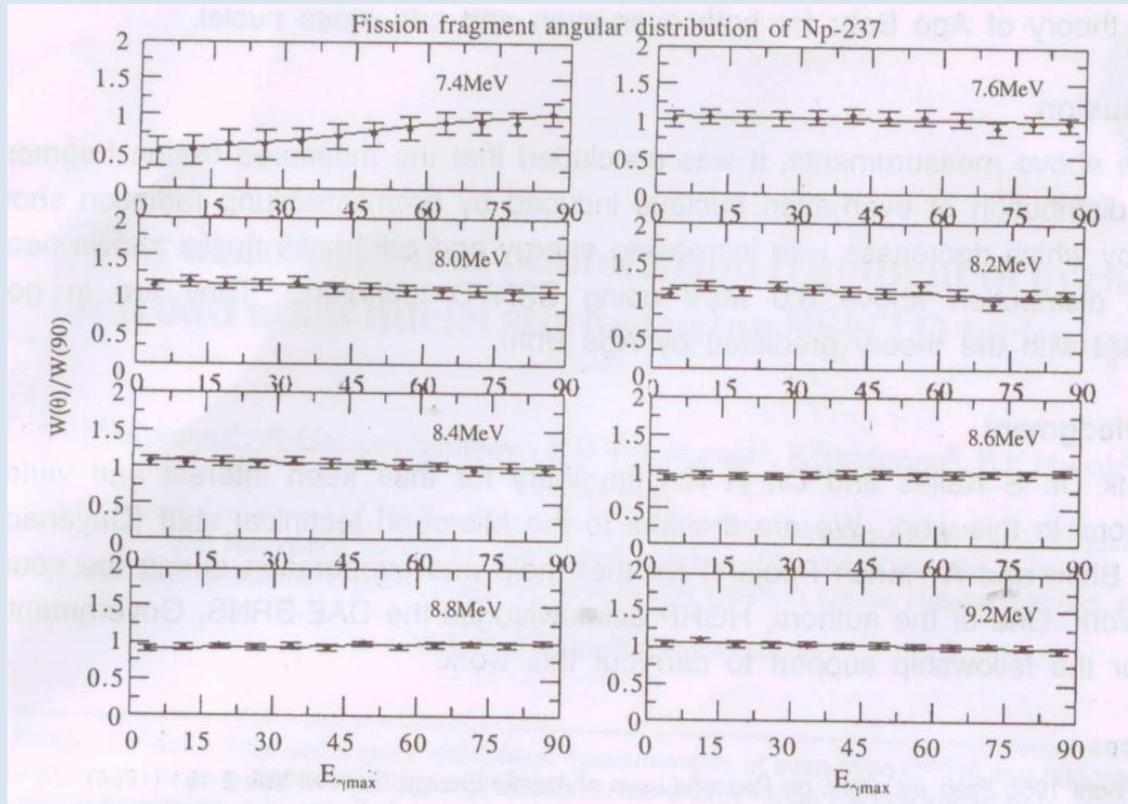
Photofission fragment angular distribution measurements of even-even mass  $^{232}\text{Th}$ ,  $^{238}\text{U}$  and odd mass  $^{237}\text{Np}$  nuclei were carried out using bremsstrahlung radiation from the microtron. SSNTD technique was used to record the fission tracks. The results reveals that the odd mass nuclei shows nearly isotropic distribution.

The photofission cross-section was calculated using the angular distribution of fission fragments and the results were compared with those obtained using the code EMPIRE-II and various barrier parameters of the RIPL-1, RIPL-2 libraries and with the new analytical fission barrier formula based on the HugenholtzeVan Hove theorem. The results are in good agreement with the prediction of the RIPL-1 barrier parameter and analytical fission barrier formula.





# Photofission Studies



Fission fragments angular distributions of  $^{237}\text{Np}$





## Neutron converter facility

The bremsstrahlung photons from the Microtron are made to fall on cylindrical beryllium discs of appropriate dimension to get fast neutrons. The fast neutrons are thermalised using high density polyethylene (HDPE), borated wood and borated rubber.

- Accelerator based pulsed neutron sources can provide neutrons of thermal energies (0.025eV) to several MeV
- The advantages of accelerator based neutron sources are that there will not be any radioactive waste, wide and easy accessibility and availability of variable broad energy spectrum of neutrons.
- Beryllium has been selected for the purpose as it has a low reaction threshold (1.67 MeV) for neutron production.
- Neutron converter design and MCNP simulation have been carried out to get optimum neutron yield. The simulation was carried out for various thicknesses of beryllium target.
- A neutron yield of  $10^9$  n/sec was obtained theoretically for beryllium thickness of 6cm at 50 Hz PRR





## Studies on Relative Biological Effectiveness

Studies in the area of Radiation Biophysics are being carried out to work out all possible physical and biological parameters for electron beam from the microtron.

The study is aimed:

- to investigate radiation dose rate effects on survival and gene conversion responses of yeast and bacteria
- Chromosome aberration as well as micronucleus induction in human peripheral lymphocytes with an emphasis on physical and biophysical modifying factors like irradiation, dose rate and exposure time.

The induction of micronuclei in PBLs exposed to both 8 MeV electrons and Co-60 gamma radiation has been characterized, with the objective of exploring this endpoint as an indicator of biological damage.





## **Radiation Biophysics Studies**

The radiation damage of living tissues and cells has attracted attention for many reasons

Ionizing radiation deposits energy in the form of discrete radiation tracks in cells leading to a spectrum of DNA lesions along the tracks via the action of free radicals leading to un-repaired or mis-repaired, gene mutations, chromosomal aberrations, or cell death.

The assessment of cytogenetic damage is important to understand the genetic risk in radiation protection. It is also of particular interest in bio-dosimetry, since cytogenetic damage is almost radiation-specific.

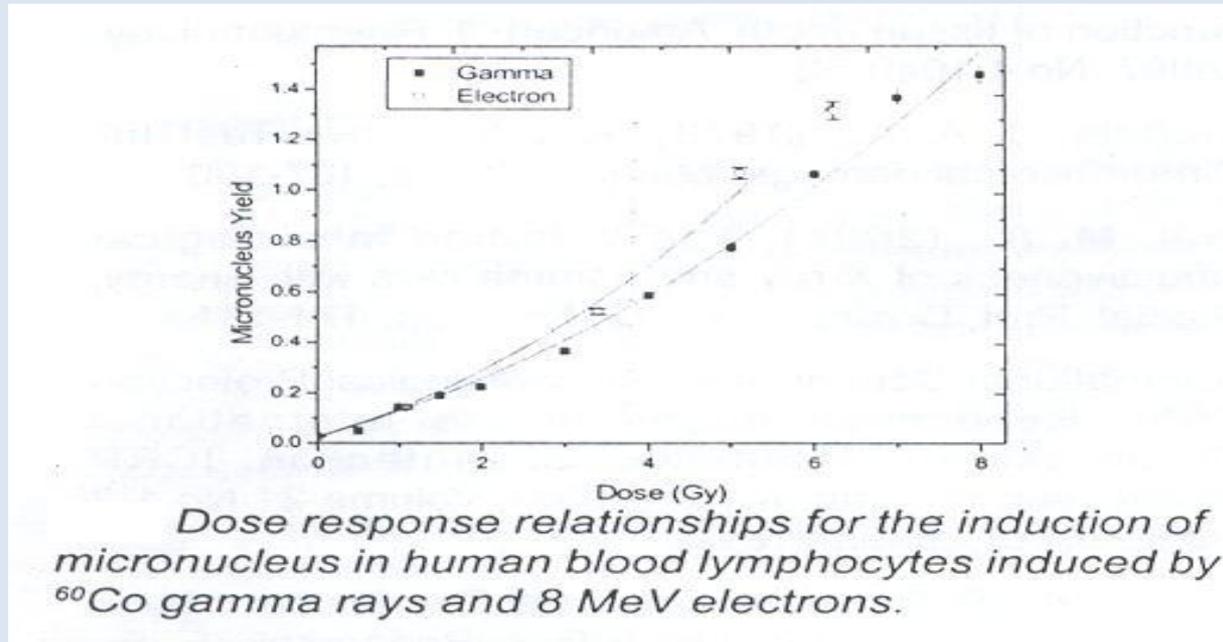
Among many, chromosomal aberration analysis and micronucleus assay in human peripheral blood lymphocytes (PBLs) are the most reliable techniques.

The micronucleus assay in human PBL is a sensitive indicator of radiation damage and could serve as a biological dosimeter in evaluating suspected over exposure to ionising radiation. MN frequency as a measure of chromosomal damage has also extensively been employed to quantify the effects of radiation dose rate on biological systems.





## Studies on Relative Biological Effectiveness



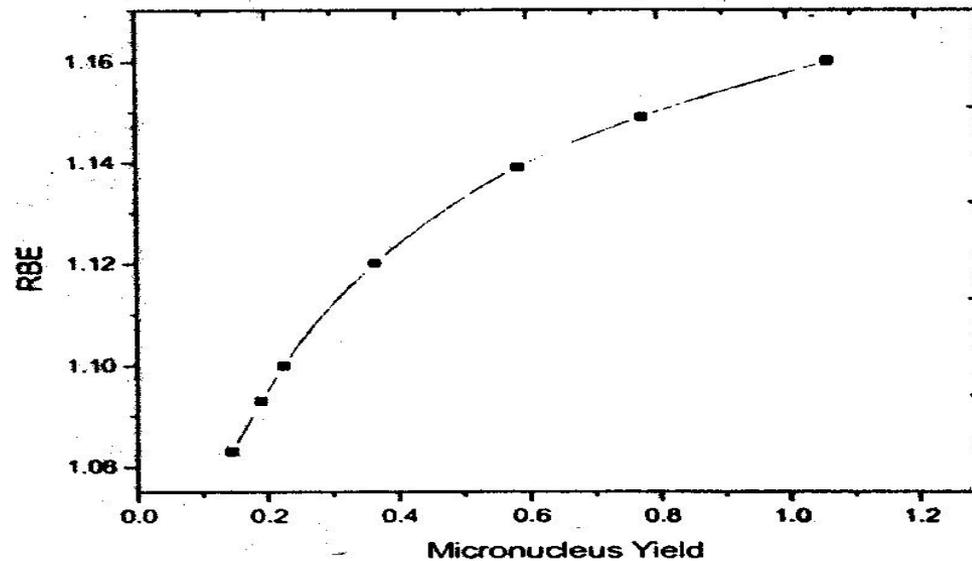
To study the dose rate effect, blood samples were irradiated to an absorbed dose of  $(4.7 \pm 0.2)\text{Gy}$  at different rates and cytogenetic damage was quantified using the micronucleus assay.

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## Studies on Relative Biological Effectiveness



*The variation of RBE values as a function of micronucleus yield induced by 8 MeV electrons in blood lymphocytes.*





## Studies on Radiobiology

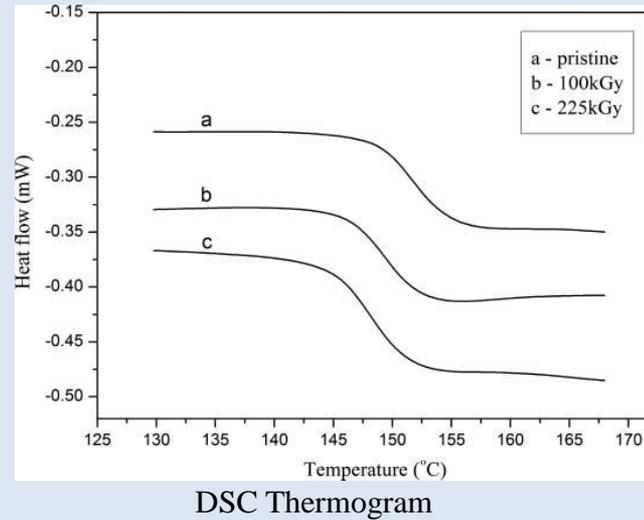
- The mechanism for repairing radiation damage, found in diverse organism, from yeast to humans, is remarkably similar. The universality of these mechanisms makes yeast particularly useful for studying and demonstrating how most cells respond to radiation exposure.
- An attempt has been made to quantify the dose rate effect on yeast cells *Saccharomyces cerevisiae* D7, X2180 under euoxic and hypoxic condition.
- From the study on diploid yeast cells it is found that the presence of oxygen enhances not only the induction of radiation damage but also its efficient repair.





# Irradiation Effects on Materials

## Lexan polycarbonate films



The glass transition temperature (T<sub>g</sub>) for pristine sample was 150°C  
100kGy – 146°C and 225 kGy – 143°C

Shift of T<sub>g</sub> to lower temperature reveals that irradiation leads to chain scission and subsequently reduction in molecular weight





## Irradiation Effects on Materials

### Lexan polycarbonate films

*UV-Visible spectroscopy* - decrease in optical energy gap, optical activation energy and increase in number of carbon atoms per cluster with increase in electron dose.

*FTIR spectroscopy* - The chemical changes due to chain-scission and reconstruction.

The correlation of positron lifetime study with optical measurement is obtained and an attempt is made to understand the electron irradiation induced microstructural modifications within the polymer.

*XRD pattern* - crystallite size and percentage of crystallinity decreases due to the breakage of bonds resulting change of semicrystalline structure of polymer to amorphous.

*SEM* - blisters formation of various sizes and finally gradual degradation in the network structure.

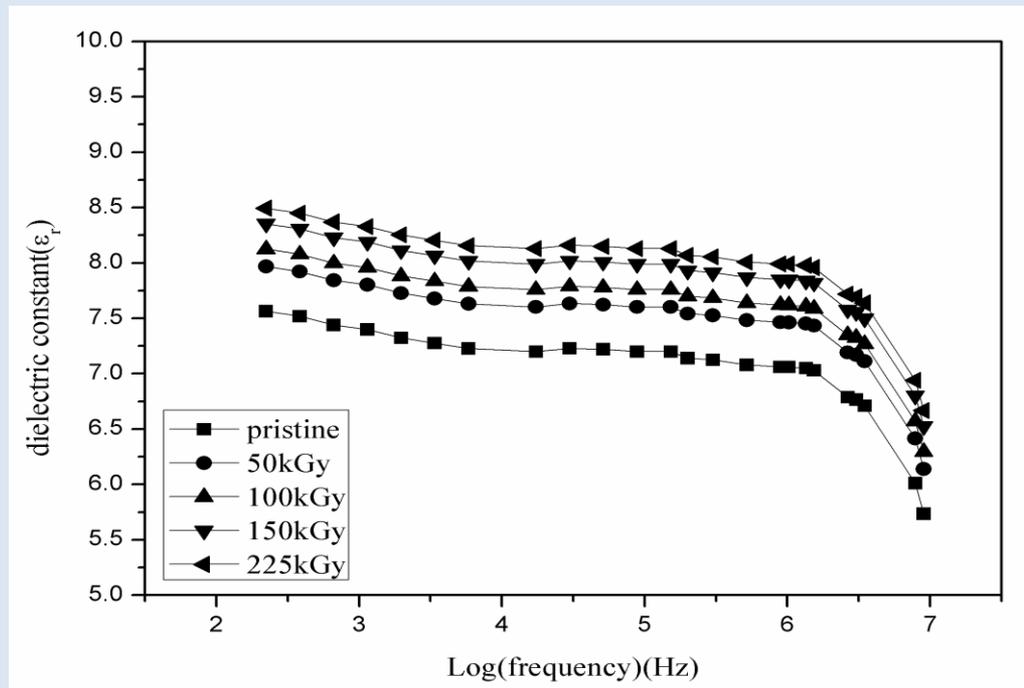
*Photoluminescence technique* - formation of defects and chromophores, and presence of impurities, additives and unsaturation have been studied





## Irradiation Effects on Materials

a.c conductivity and dielectric constant increase with increase in electron dose - due to the breakage of chemical bonds which increases the number of free radicals.



Dielectric Constant Vs Log (frequency)





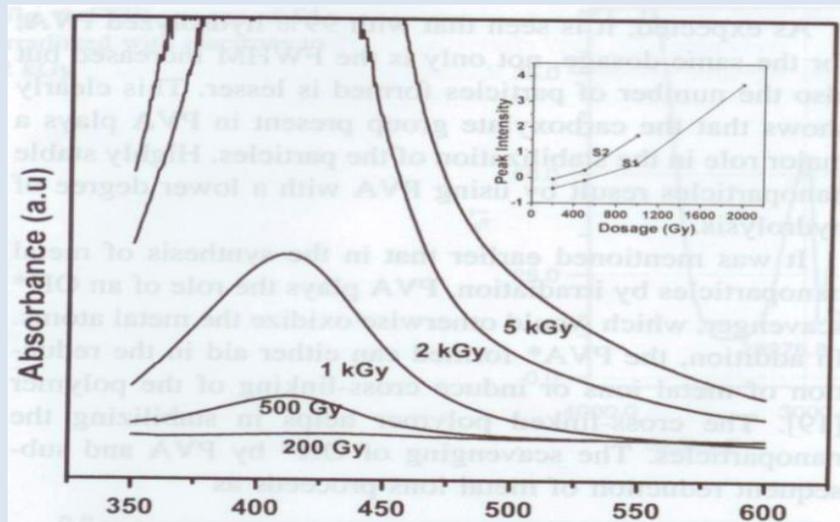


## Radiation induced nano-particles synthesis

Stable, non toxic Ag nano-particles synthesized by irradiating an aqueous solution of AgNO<sub>3</sub> and Polyvinyl alcohol (PVA) having two different degree of hydrolysis acting as the stabilizer.

The size, shape, and the rate of formation of the nanoparticles depend on the final dosage, as well as the weight ratio of AgNO<sub>3</sub> and PVA.

The formation of Ag nanoparticles and their size were established through UV–Vis spectroscopy (peak at 410nm) and Transmission Electron Microscopy (TEM) analysis, respectively. Increasing the irradiation dosage seem to favour the formation of polygonal nanostructures.



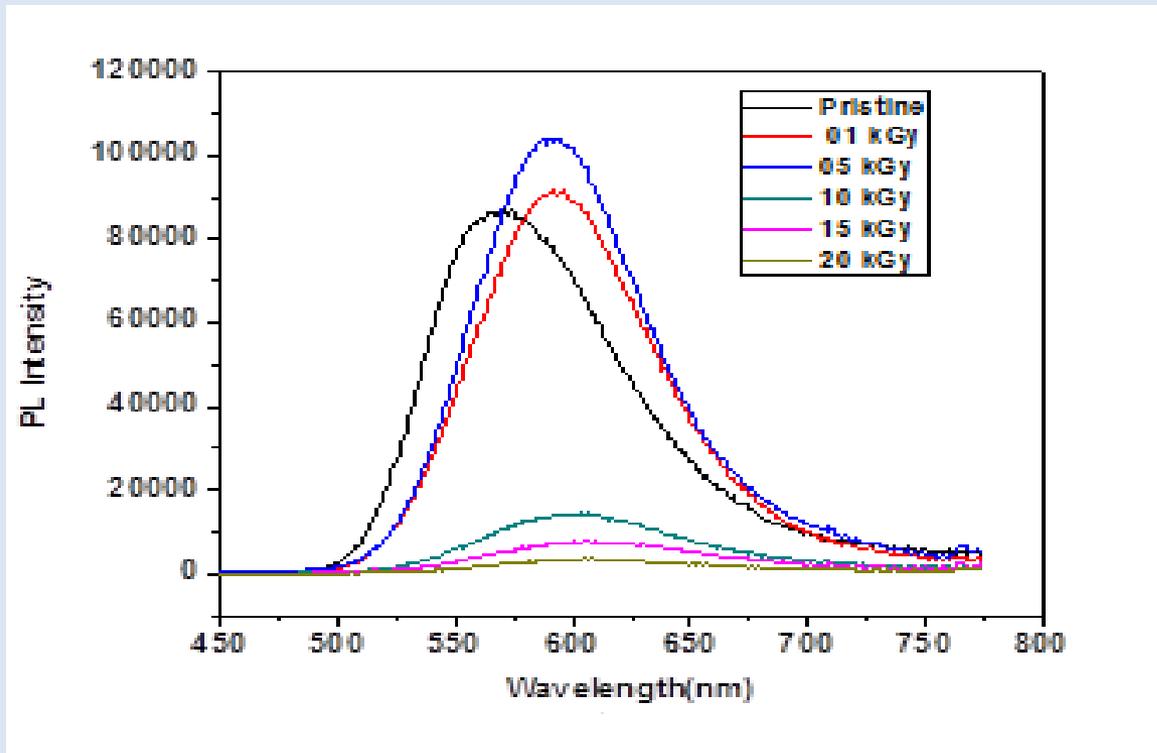
Absorption spectra of AgNO<sub>3</sub>:PVA for different electron doses. Inset shows variation of peak intensity with dose





## Radiation effects on Quantum dots

A novel one pot synthesis of CdTe Quantum dots (QD) using hydrothermal technique has been developed using  $\text{Na}_2\text{TeO}_3$  as Te source and  $\text{CdCl}_2$  as cadmium source. CdTe QD was exposed to various electron doses, ranging from 1kGy to 20 kGy. The characterisations of the samples have shown interesting changes in photoluminescence properties. An increase in emission intensity for doses up to 5 kGy and decrease in emission intensity for doses more than 5 kGy were observed



Photoluminescent Spectra of CdTe quantum dots at various electron doses

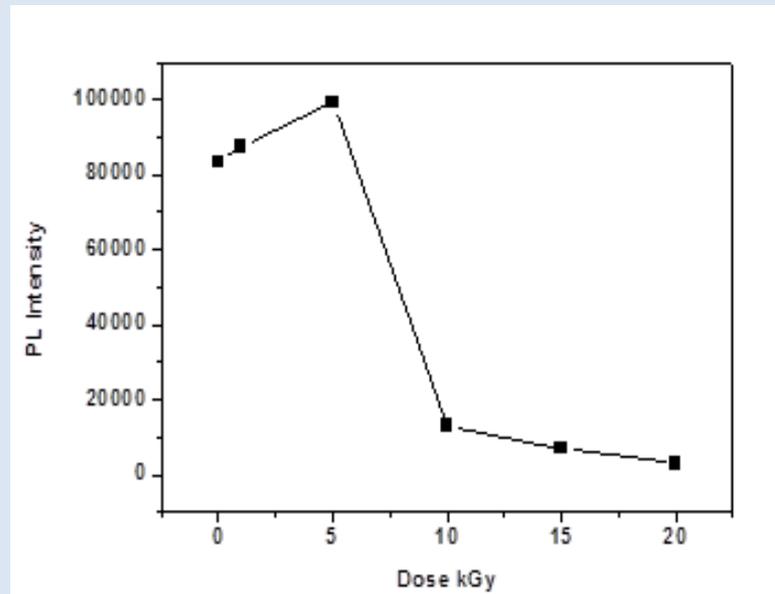




Photoluminescent yield (peak) at different electron doses

The results were ascertained using time resolved emission spectroscopy and X-ray photo electron spectroscopy of the QDs. The CdTe QDs can be used in Bio tagging as CdS layer formed (upon irradiation) on CdTe Core is Bio friendly and formation of CdS can enhance photo emission, giving rise to bright emission for easy detection of tagged DNA (any bio material).

aqueous solution of CdTe with thioglycolic acid (TGA) as capping agent





## **Other methods of Nanoparticle synthesis**

- from Mushroom extracts - Antimicrobial property of Ag nanoparticles
- Anticancer property of Au nano particle

### **Radiation effects on thin films**

Silver particulate films deposited on electron beam irradiated polystyrene (PS) coated substrates held at a temperature of 455K at a constant deposition rate of 0.4 nm/s - polymer-metal interaction can be brought about in inert polymers like PS by electron irradiation.

The results indicate that the films deposited on PS irradiated to a dose of 20kGy and 25 kGy give rise to smaller clusters with smaller inter-cluster separation, better suited for sensor applications. The induced polymer-metal interaction is attributed to the creation of free radicals due to electron beam irradiation





## **Program for users**

Workshops, Seminars and Users Meeting on different areas of research are being organized to encourage both in building up the laboratory facilities and to use the facility for carrying out front-line research in the field.

MAC Meeting – Research Projects - 79

## **Future plans**

Up-gradation of the existing accelerator facility with higher beam power to cater to the needs of the Microtron Users is planned with the support of BRNS.

Detailed neutron based studies on various aspects would be taken up.

Extension of Microtron facility to postgraduate students for their laboratory experiments / project works.





## Acknowledgement

**Timely support from BRNS & Concerned scientific personnel of RRCAT, Indore is gratefully acknowledged**





**THANK YOU**

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