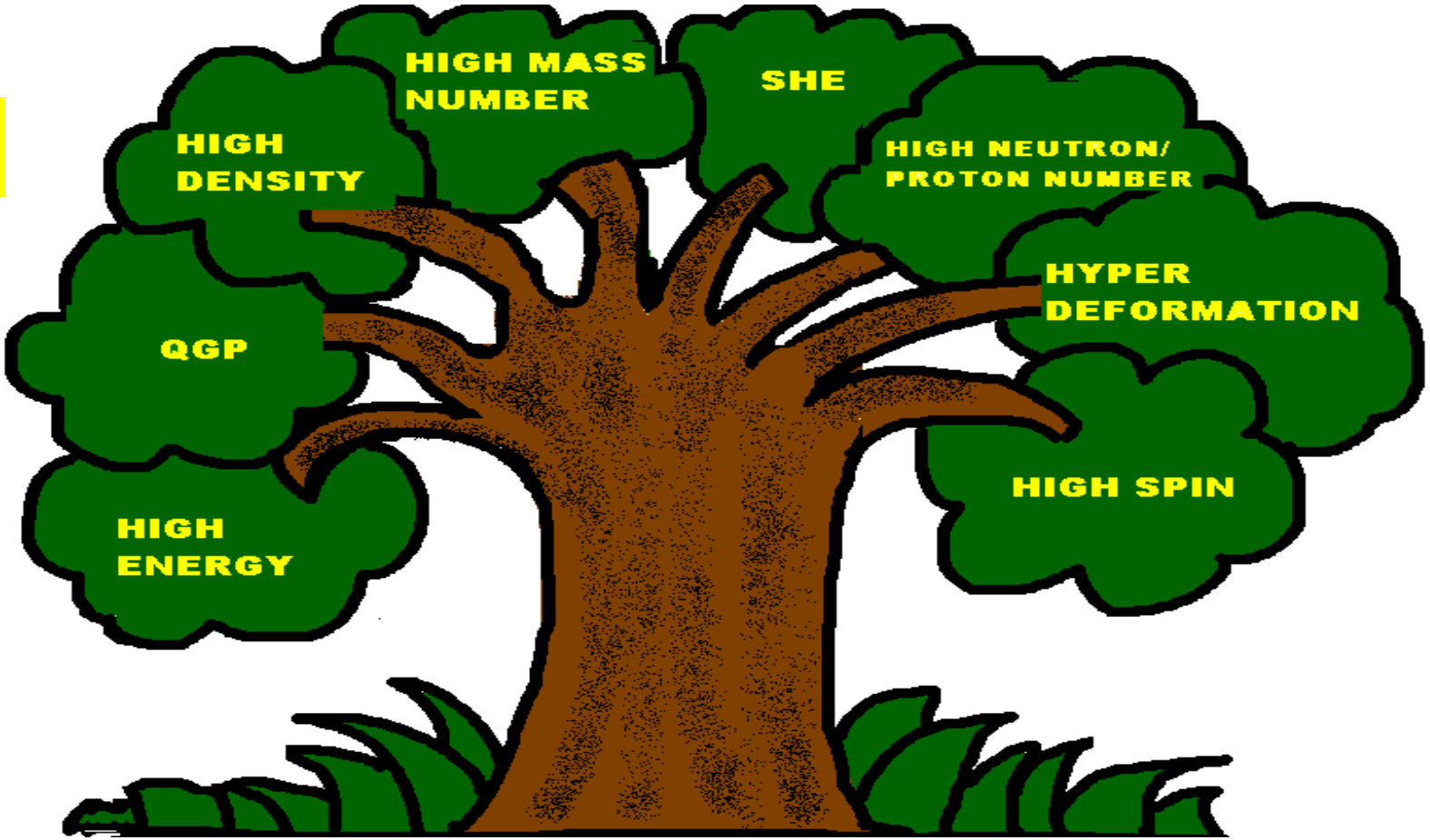
Nuclear Science, Technology and Society

S. Kailas
UM-DAE Centre for Excellence in Basic Sciences, Mumbai

Growth of Nuclear Physics Research

300 Nuclei



3300 Nuclei

Accelerators

Detectors

Electronics

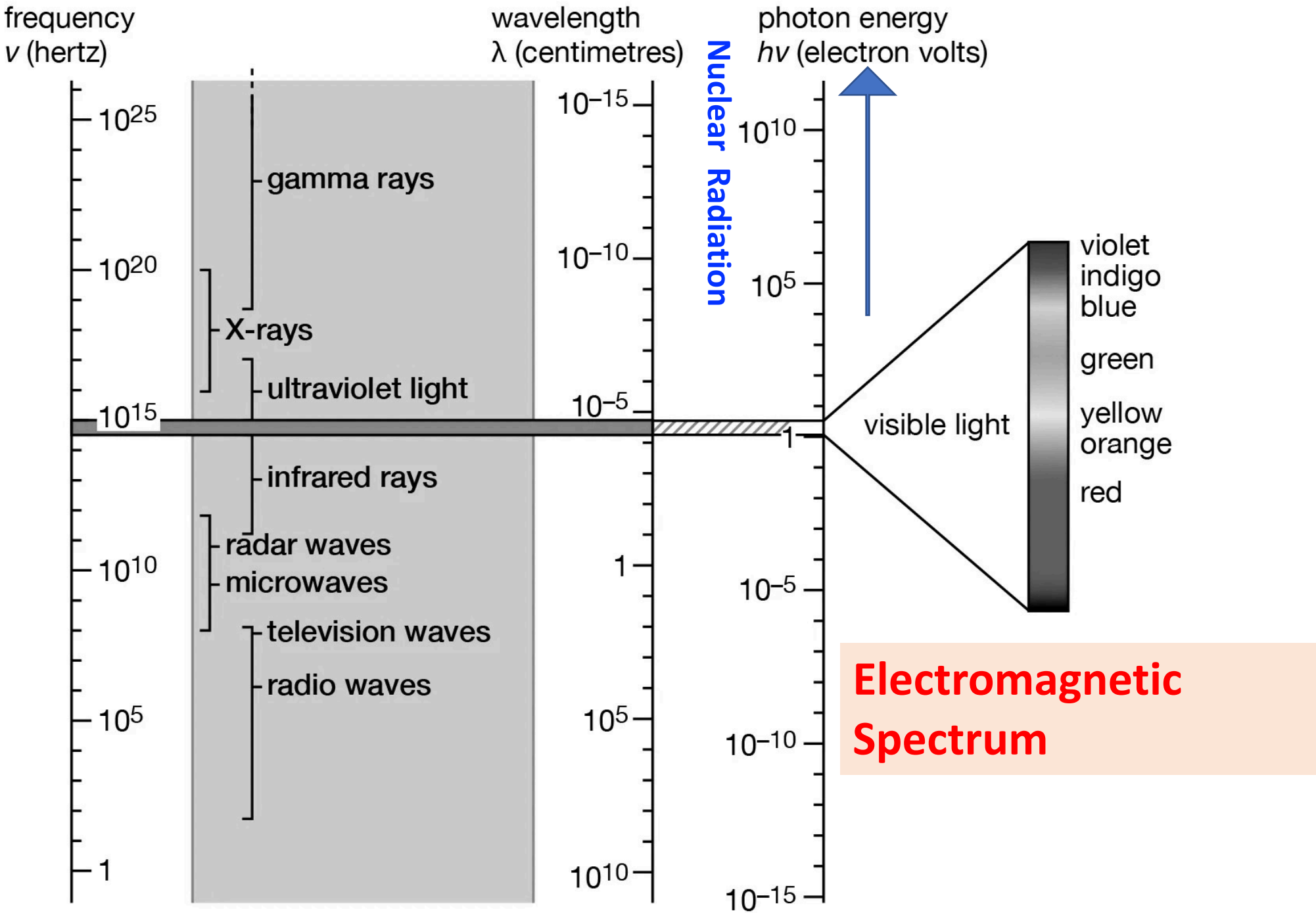
Computers

Nuclear Science
(Nuclear Physics, Nuclear Chemistry and Radiation Biology)

Tools employed for carrying out Nuclear Science Research

: Charged particle accelerators
: Research Reactors
: Different types of nuclear radiation detectors
: High density electronics
: High speed computing

All of them have contributed to the development
Of technologies of great use to society


frequency
v (hertz)
wavelength
λ (centimetres)
photon energy
hv (electron volts)
Nuclear Radiation
10^25
10^20
10^15
10^10
10^5
1
gamma rays
X-rays
ultraviolet light
infrared rays
radar waves
microwaves
television waves
radio waves
10^-15
10^-10
10^-5
1
10^5
10^10
10^10
10^5
1
10^-5
10^-10
10^-15
visible light
violet
indigo
blue
green
yellow
orange
red
Electromagnetic Spectrum

Nuclear Radiation(NR) is an ionizing radiation

Arises due to nuclear process and is a part of nuclear science

It is present everywhere –

Where we live, what we eat, drink and breath

----Within safe limits for humans

NR consists of protons, neutrons, alphas, gammas.....

Natural Background of Nuclear Radiation-

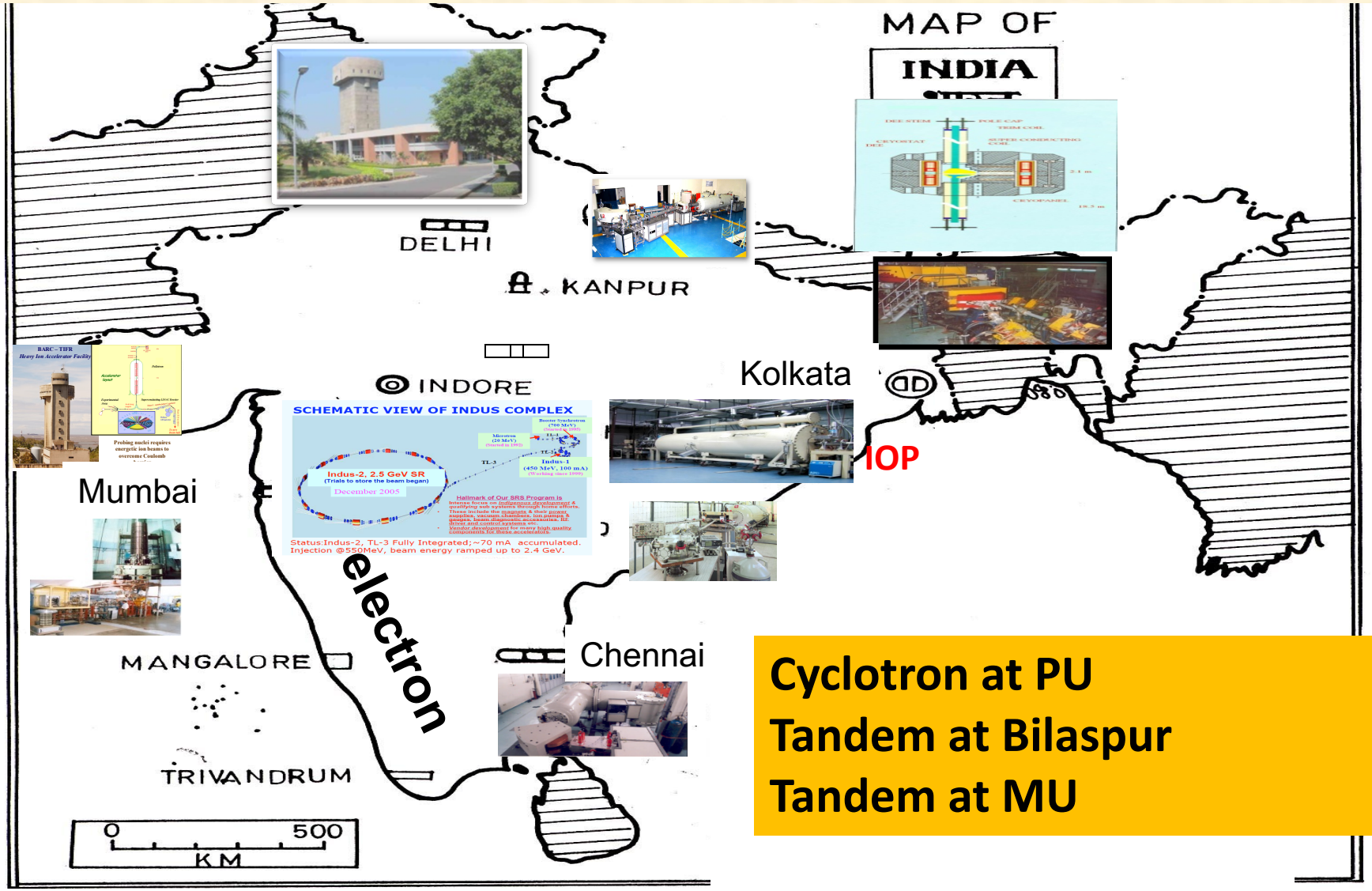
- Cosmic Rays (high energy particles)
- 40K, 232Th, 238U decay products/ gammas

-within safe limits for us and we live with this

Manmade – NR from Nuclear reactors, Charged particle accelerators,

..- NR can be controlled and is a small fraction of natural background and safe

Accelerator Map of India



Cyclotron at PU
Tandem at Bilaspur
Tandem at MU

There are nearly 30000 accelerators both big and small and of Different types (as per 2018 data)

60% are used in Industry

30% in Healthcare

Around 1 % in Basic research

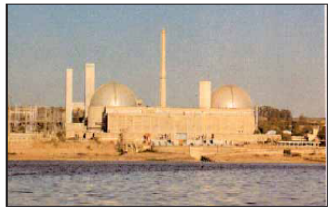
Accelerators developed for Nuclear and Particle physics have tremendous applications in multidisciplinary areas

Accelerators employ SC and RF technologies in plenty
LHC has nearly 10000 SC magnets!

Nuclear power plants in India

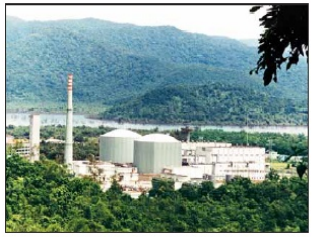
- 8180 MW (20 PHWRs, 2BWRs,2LWR) in operation
- 500 MW (1 PFBR) under construction***
- More in the pipeline

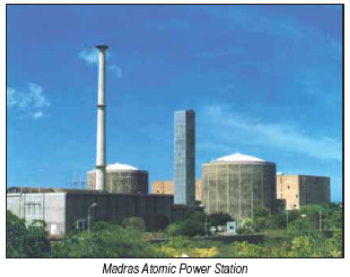

Narora Atomic Power Station


Panoramic view of Rajasthan Atomic Power Station


Construction work at Tarapur Units-3 and 4


Kakrapar Atomic Power Station


Kaiga Atomic Power Station

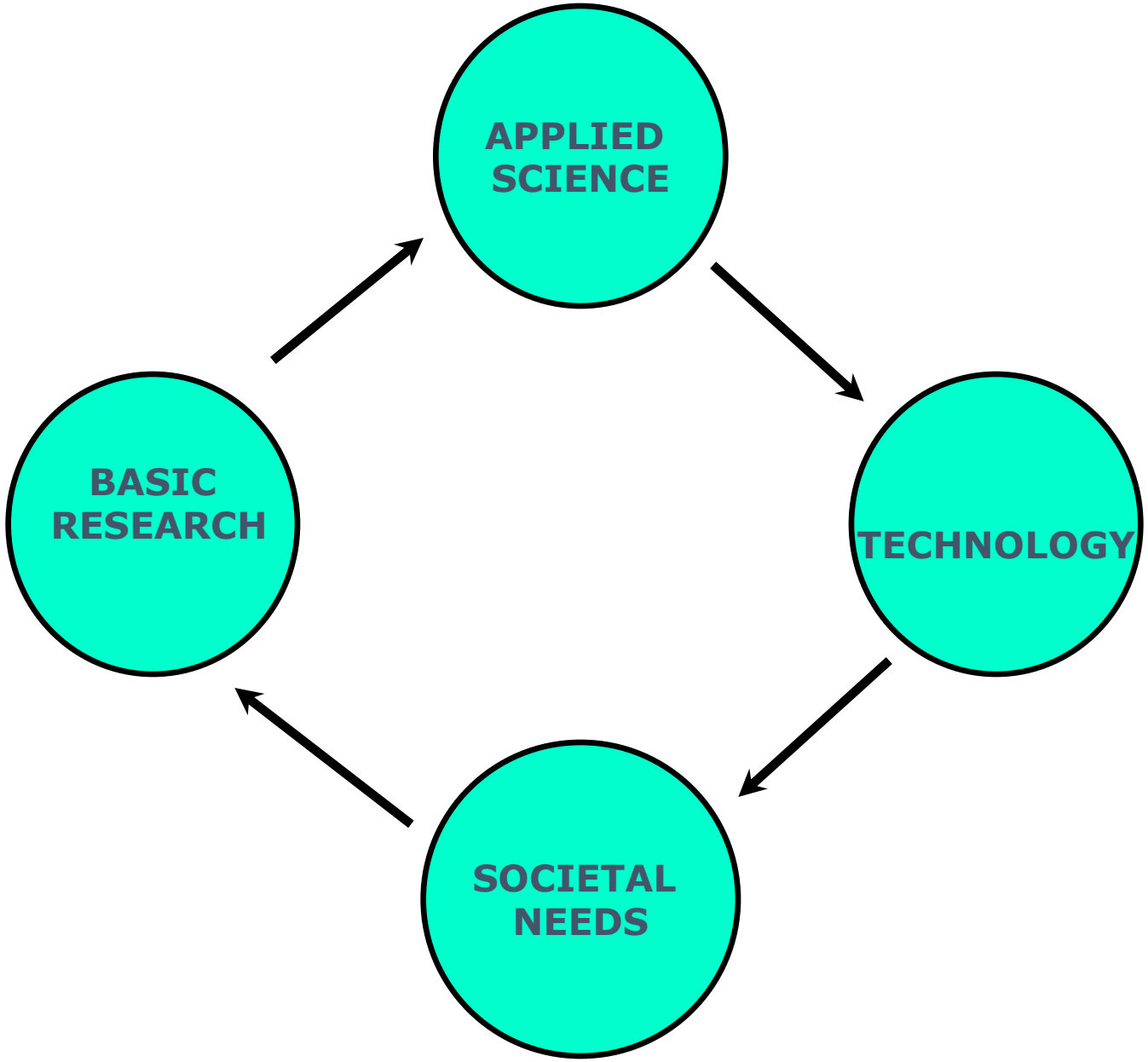

Madras Atomic Power Station

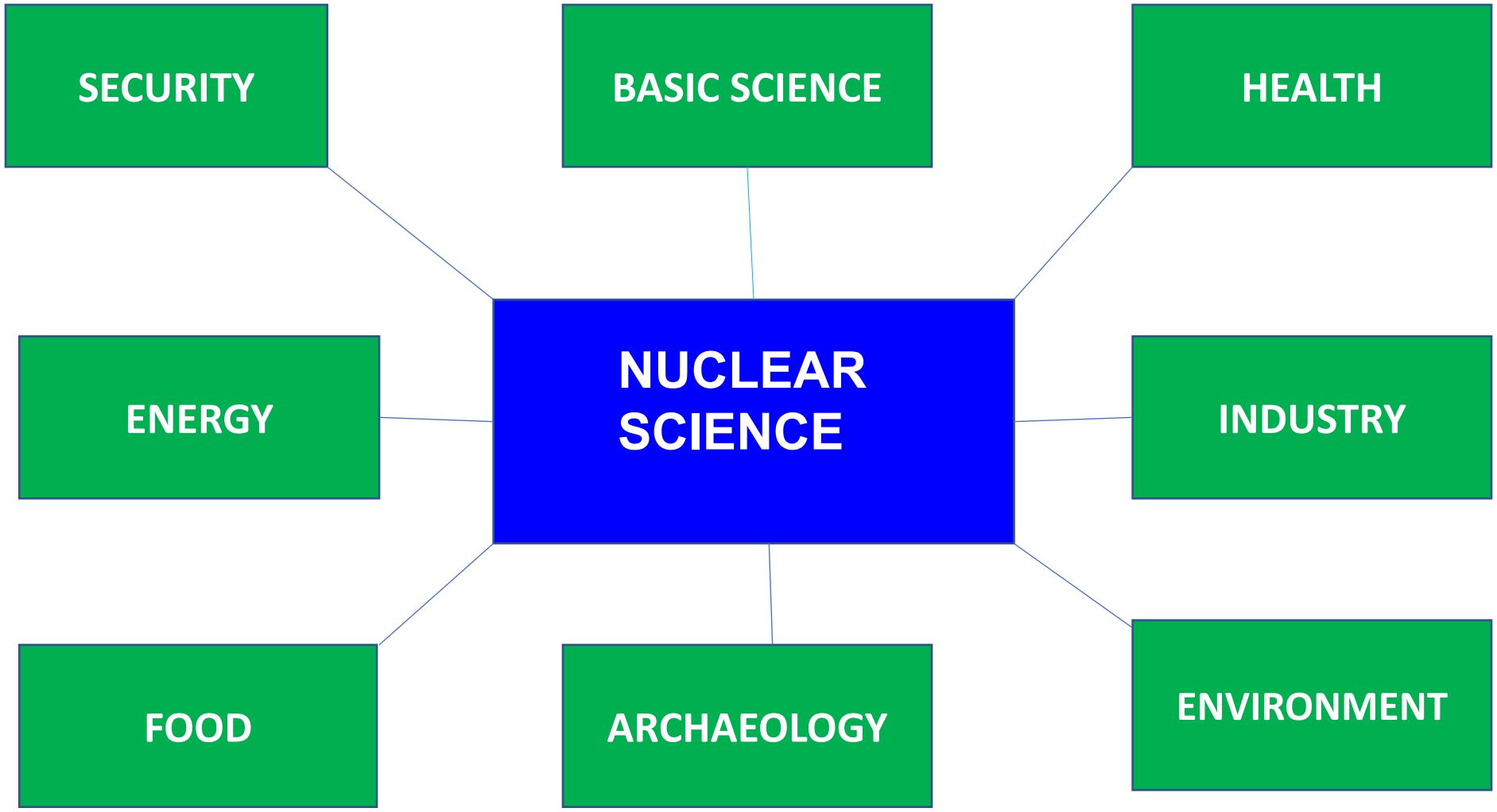
Yesterday's Science Today's Technology

Maxwell	EM theory	Electrical engineering
Onnes	Superconductivity	Magnets, SQUIDS, RF accelerators
Purcell..	NMR	Mag.Res. Imaging (MRI)
Roentgen	X-rays	Medical Diagnosis
Bardeen..	Transistor	Electronics
Hahn and.	Nuclear Fission	Reactors for power
Strassmann		
TimBL	WWW	Internet communication
Sauli	Radiation Detectors	Medical imaging etc.
	for basic research	

Research and Technology are two sides of the same coin

NUCLEAR SCIENCE IN SOCIETY

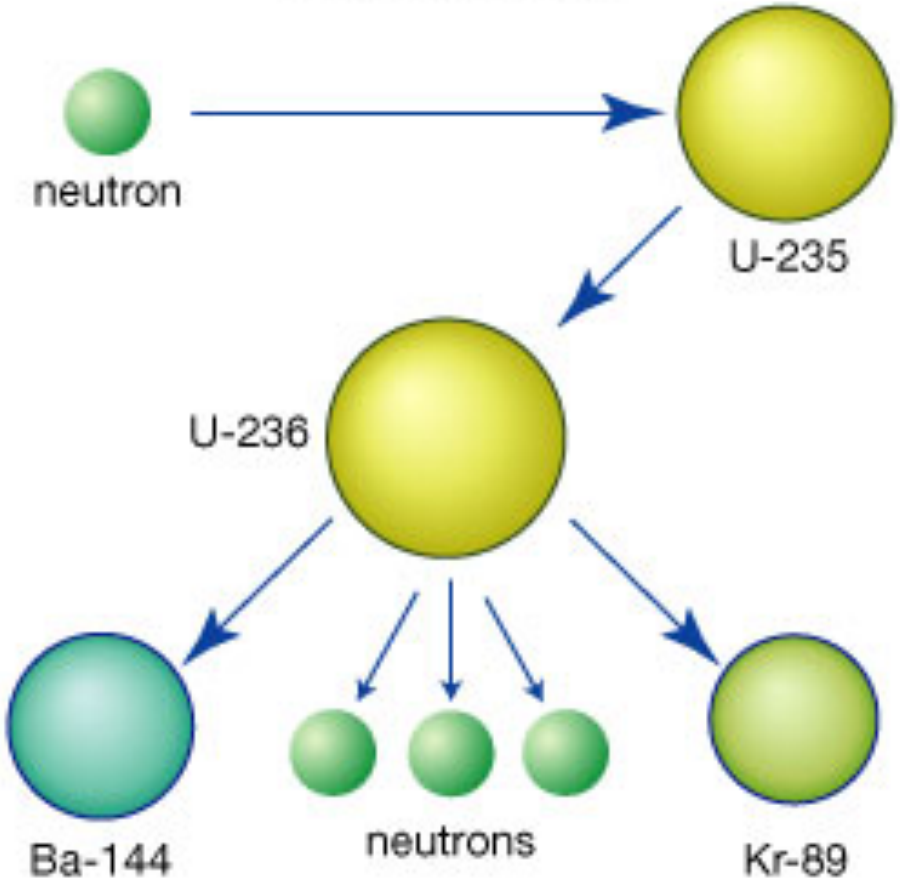



SECURITY
BASIC SCIENCE
HEALTH
ENERGY
NUCLEAR SCIENCE
INDUSTRY
FOOD
ARCHAEOLOGY
ENVIRONMENT

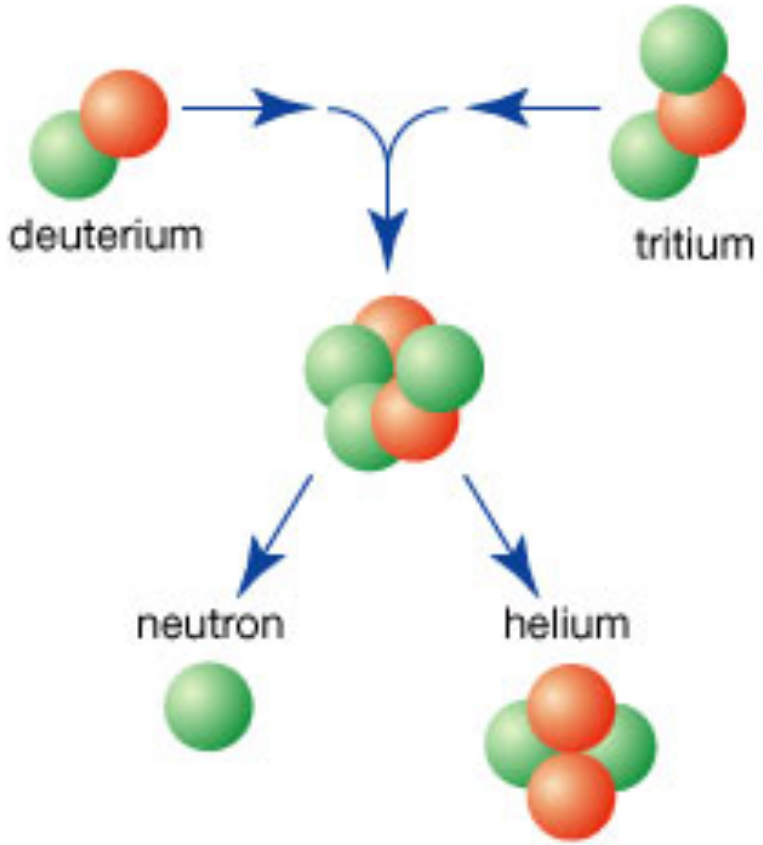
NUCLEAR ENERGY

Nuclear Energy

Nuclear Fission



Nuclear Fusion



Energy is Released in Fusion and Fission Reactions

Role of Renewable Energy Sources

We need: per capita electricity of 2000 kWh/y by 2070---

India would need to generate 3400 TWh/y(estimated).

All renewable energy sources put together,
the potential is only 1299 TWh/y.(438 TWh/y from solar)

Concluded that in future when fossil fuels are exhausted
Renewable sources alone will not be sufficient for meeting India's needs.
S.P.Sukhatme, Cur.Sci. 101 (2011) 10th sept

Courtesy : Dr. R. Chidambaram

Nuclear Energy is an inevitable option In the energy mix of our economy **(Dr. R. Chidambaram)**

It is safe, economical and sustainable –
It requires less space when compared to Hydro and Coal based Plants and emitting less or no CO2

India has the resources to build and operate Nuclear Reactors. India has a high safety record in running Nuclear reactors for more than 60 years

India to enhance the share of Nuclear Energy in a fast time scale – international collaboration needed.
Also participation Of Industry and Academic Institutions

NUCLEAR FISSION ENERGY

In the world there are ~ 450 reactors-- 30% of world electricity.
Even UAE has a nuclear reactor now!

About 50 new reactors are under construction all over the world.

In India we have currently 24 Nuclear reactors Operational generating nearly 8180 MWe. Another 9 reactors are under Construction 7300 MWe (including the one based on Pu. All other Reactors are based on U)

More reactors are being planned. India wants to achieve 100 GW
By 2047 (currently less than 10 GW)

Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India SHANTI Bill 2025. DAE and Govt. of India Initiative

HEALTHCARE

Radioisotopes Required in Healthcare

Tumor/ cancerous cells absorb more Glucose than Normal cells.
18F used
Distinguish cancer//Non Cancer cells

Iodine has great affinity for Thyroid –
123,131I used
Diagnose Thyroid disorder

Slower washout of Thallium from compromised but viable myocardial tissue as compared to normal ones- 201Tl used
Functioning of heart

Radioisotope	Half-life	Radiation	Nuclear Reaction for Production
131 I	8 days	β Eγ=364,637 keV	130Te(n, γ)131Te β decays to 131I Also as fission fragment
99mTc	6 hrs	IT Eγ =140.5 keV	98Mo(n, γ)99Mo β decay to 99mTc 100Mo(n,2n)99Mo β decay to 99mTc
18F	110 mins	Beta+	18O(p,n)18F
201Tl	73 hrs	EC Eγ=135,167 keV	203Tl(p,3n)201Pb β+ decay to 201Tl
123 I	13.3 h	EC Eγ = 159 keV	123Te (p,n) 123I
177Lu	6.7 days	β Eγ = 113,208 keV	176Lu(n, γ)177Lu

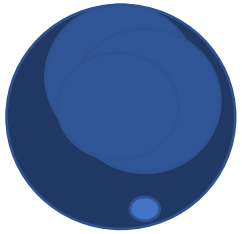
Neutron Induced Nuclear Fission on 235U as Target

Neutron

131I

Neutron

^{235}U



Two Heavy Fragments
(^{131}I and ^{103}Y)

Range of Masses
Many Isotopes

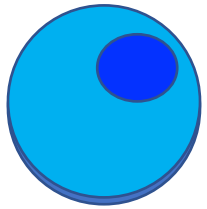
Nuclear Fission

103Y

Neutron

Proton Induced Reaction of 18O and Production of neutron and 18F

Proton



18O

Neutron

18F

Medical Cyclotron

Features of PET trace® Medical Cyclotron

- Fixed Beam Energy variable current
- 16.5 MeV (H-), 75 µA single beam, 40 µA dual beam
- 4 MeV (D-) 60 µA single beam, 30 µA dual beam

- Radionuclides that can be Produced
- 18F, 11C, 13N & 15O

Medical Therapy
~350 e-LINAC
~24 CYCLOTRONS
~ 200 Radioisotope Based (60Co.....)

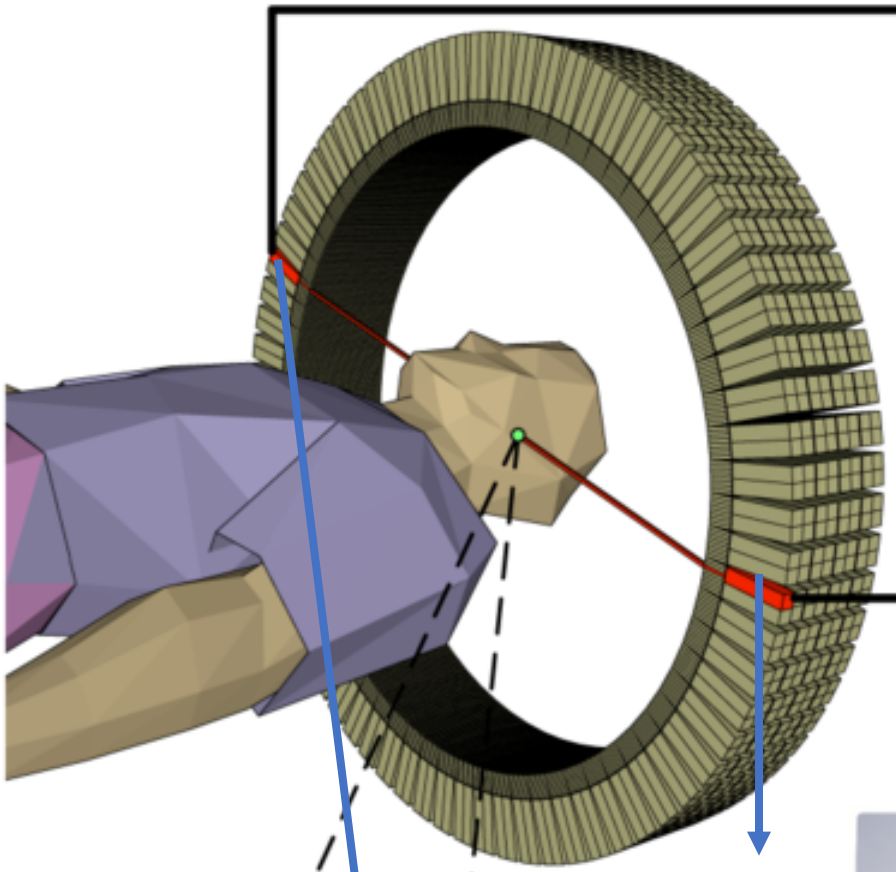
TMH/ RMC, Mumbai

Located in Hospital

30 MeV Medical Cyclotron at Kolkatta

200 MeV Medical Synchrotron At Chennai For Cancer Therapy

200 MeV Medial Synchrotron At TMC/ACTREC Mumbai

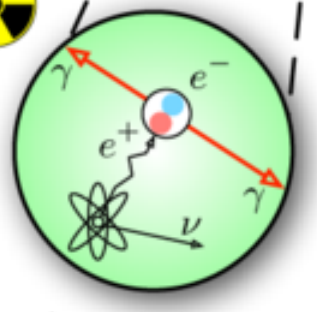


Radiographics 14,523 (2004)

Coincidence Processing Unit

Sinogram/ Listmode Data

Image Reconstruction



Annihilation

Scintillation Detectors BGO,LSO, GSO

bismuth germanate Bi4Ge3O12 (BGO

High Zeff

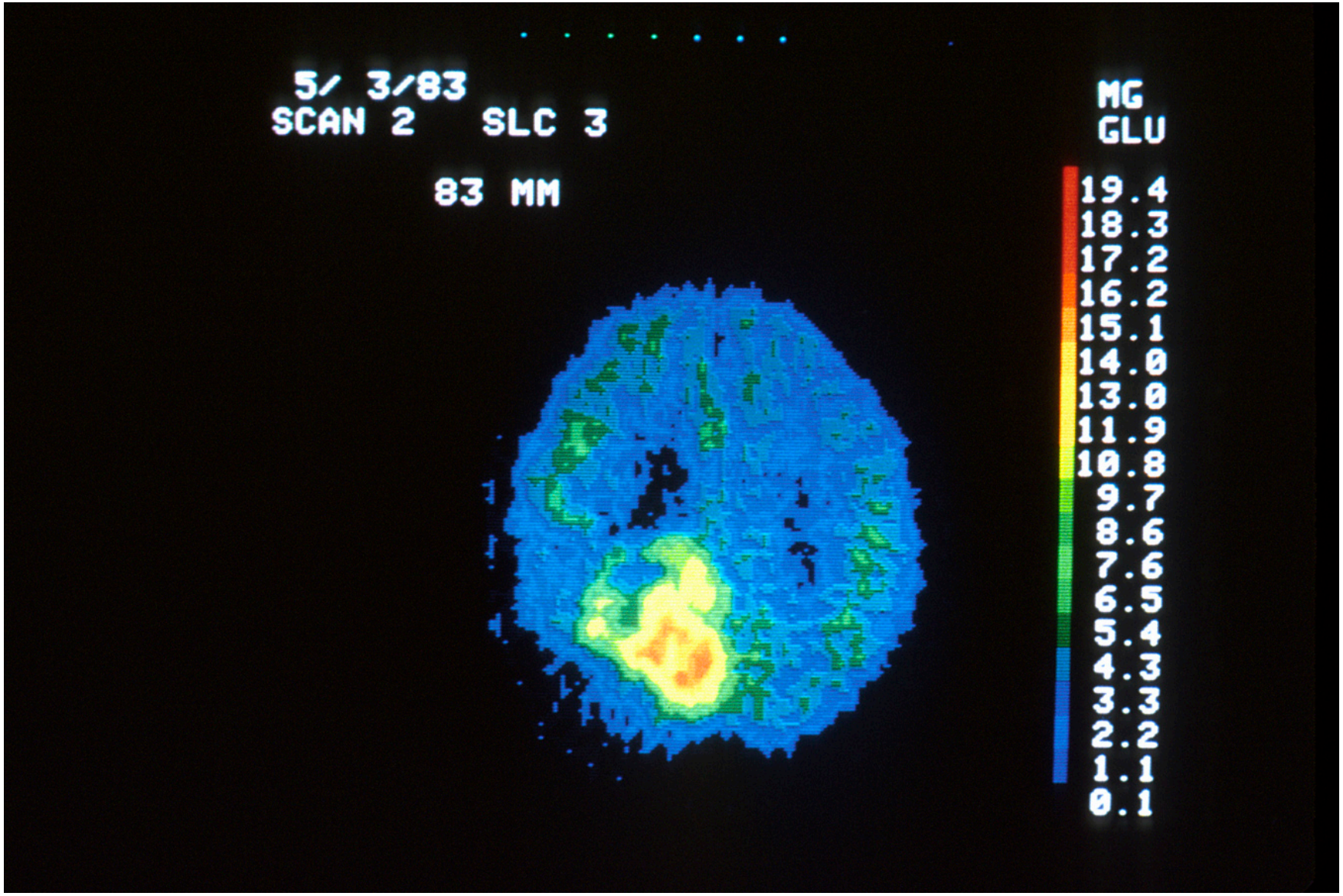
lutetium oxyorthosilicate doped with cerium Lu2SiO5:Ce (LSO)

Light output,

gadolinium oxyorthosilicate doped with cerium Gd2SiO5:Ce (GSO)

Energy resolution

Brain scan using the PET



BHABHATRON -II: Indigenous Cobalt-60 Teletherapy Unit

- First unit of Bhabhatron-II was installed at IRCS Cancer Hospital, Nellore, AP
- On December 11, 2006, the President of India has dedicated the machine to the service of the nation
- One Bhabhatron-II was gifted to Vietnam (Can Tho General Hospital)

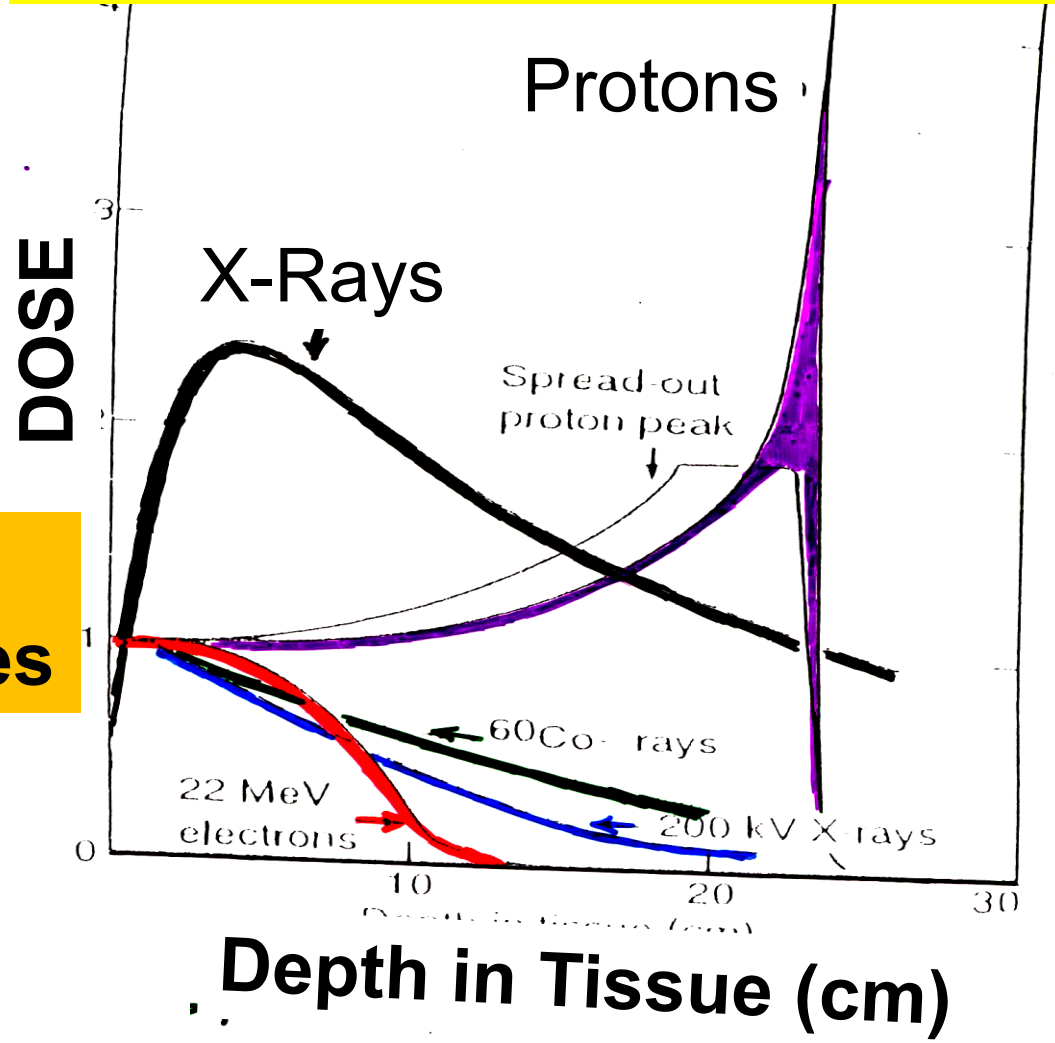
Added Features

- Battery back-up for treatments during power failures
- Optical-fibre communication
- Sleek and aesthetic appearance
- Reduced DU requirement
- At no extra cost
- More than 26 machines supplied

Bhabhatron-II

Concentrate Damage in tumor- Less damage to Healthy cells- possible using high energy Protons

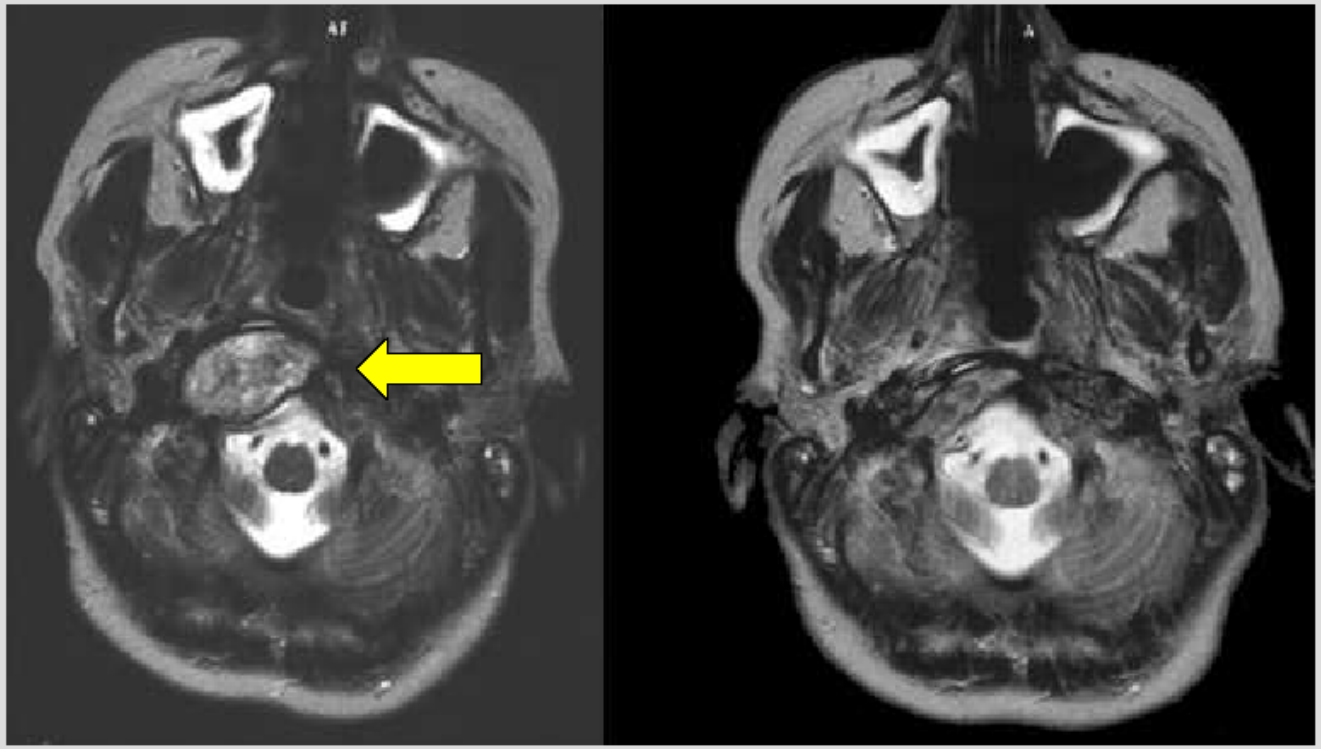
X-rays Vs Charged Particles



Proton Therapy- 250 MeV – depth varies with E

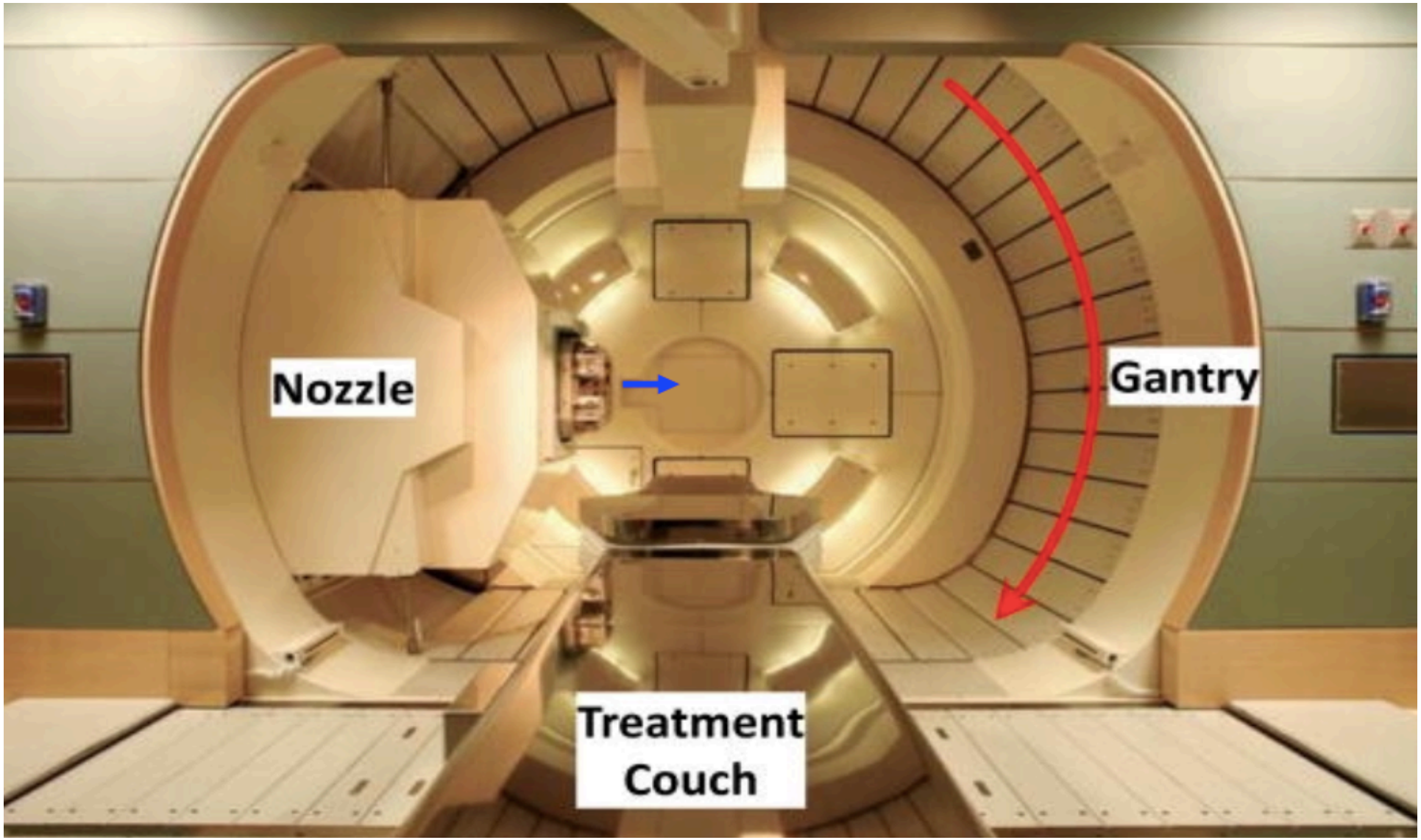
Tumor regression (Chordoma)

Hadron Therapy for Cancer



Prior to therapy

6 weeks after treatment

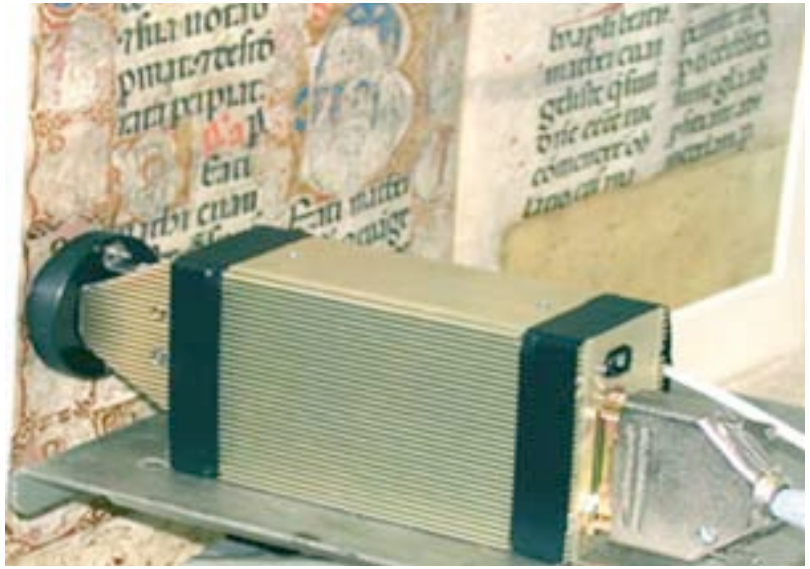


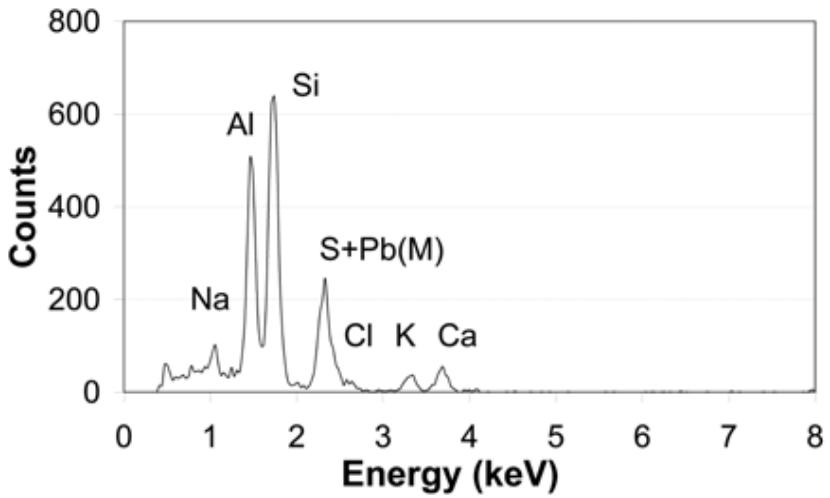
Proton Therapy Machine – Two in India

ACTREC,DAE and APOLLO

ARCHAEOLOGY

Pigments/elements used In Ancient paintings





AGLAE in France
(located in a museum)

LABEC in Italy

Small Accelerators
Dedicated to this activity

Using PIXE/PIGE

Portable PIXE(alpha)

INDUSTRY

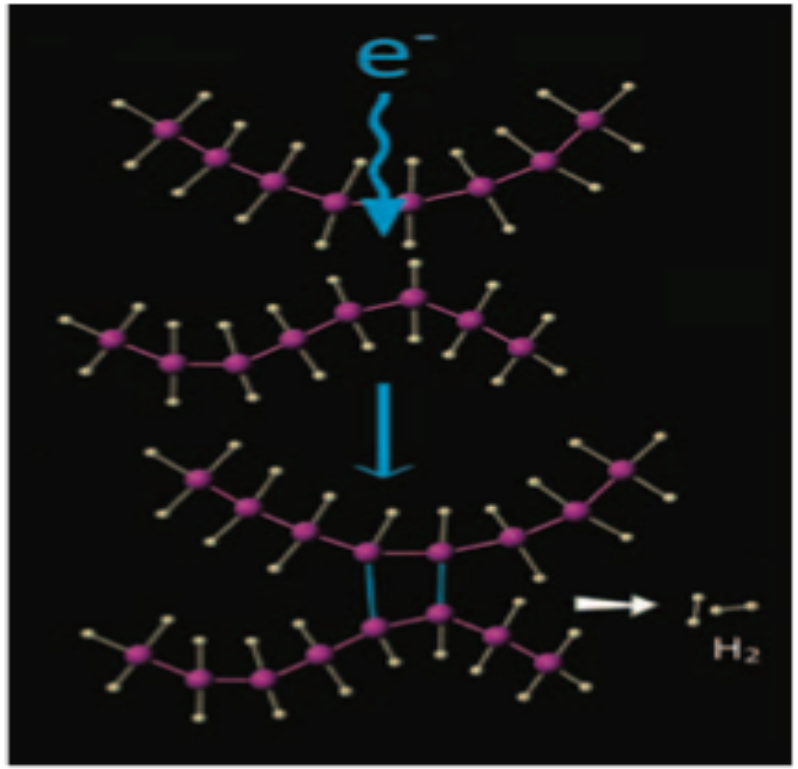
Industrial Applications

- **Ion Implantation**

  All digital electronics now depend on ion implantation-
  Semiconductor industry – change the conductivity of SC

- **Electron Beam materials processing**

Cross linking of polymers facilitated by electron beam Achieve much better mechanical, thermal and chemical Properties – cross linked polythene used as substitute to Cu piping used for water in houses



It is also possible for irradiation Of plastics to
Break the molecular chains and make them brittle by controlling the radiation dose
This way plastics can be recycled and some useful by-products like building material, tyres etc. can be made
To reduce plastic pollution

Industrial Applications

- **Electron beam irradiations**

Heat shrinkable rubbery sheets or tubes. Wrap it around cables or wires, use a heat gun over it. Instead of melting, the polymer-based product shrinks to form a tight seal – This property - after treating the rubber sheets with electron beam

Sterilization of Medical Products

Removal of toxic wastes like S and N from exhaust Of coal plants /fly ash

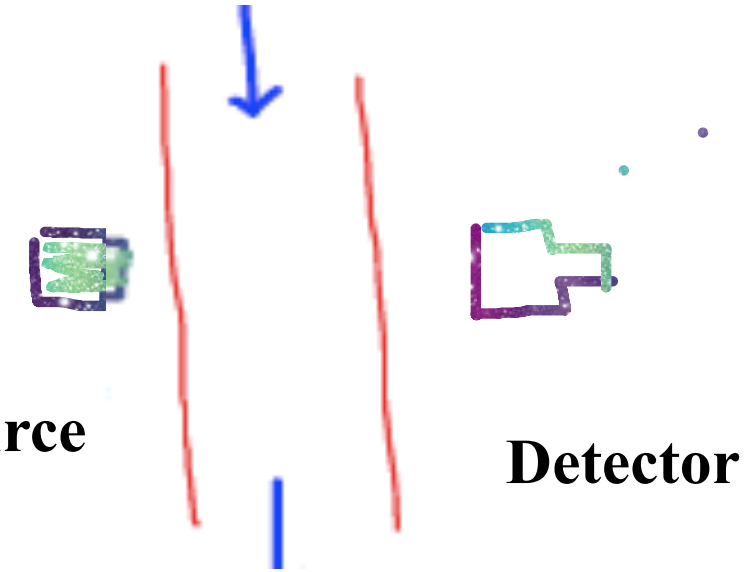
- **Radiography – inspection of welds, casting....**

Co57 Eg = 122, 136 keV. 271 days

Co60. Eg = 1170, 1330 keV. 5.27 yrs

Technique based on attenuation of gamma

Flow rate monitoring



Source

Detector

Controlling Thickness of SS sheet in Rolling mill

Process Industry

AGRICULTURE

Isotope Hydrology Applications- Radio Tracers (82Br,198Au) or stable/radioactive (2,3H,13,14C)

Identification of Ground Water Sanctuaries at Anjangaon, Amravati Dist, Maharashtra- nearby site for Borewell

BEFORE



AFTER



Courtesy DAE

Nuclear Radiation in Agriculture-42 crop varieties from BARC

Trombay Groundnuts In Farmers Field in Karnataka

Trombay Groundnuts In Farmers Field in Receding Moisture Situation

Courtesy DAE

Mutation for variability-
Natural or artificial
Gamma Irradiation Produces Accelerated Mutation
High Yielding -Early Maturity
Large Seed Size-Drought Tolerant Resistance to Biotic and Abiotic Stress

Mungbean,Uridbean,Mustard..

Nuclear Radiation in Food

- 30 % of Food and Fruit - spoilt due to poor Storage
- 40% loss from field to table.
- Nuclear Radiation used to Extend Shelf Life - No chemical used

- Insect can be disinfected
- Eliminate Food Borne pathogens and parasites
- Delay in Ripening of Fruits
- Inhibition of Sprouting

- More than 15 Gamma Irradiation Plants operational
- We have electron accelerator at Indore developed
- By RRCAT for irradiation of agricultural products
- Food quality not altered due to radiation

Electron Accelerator To Replace Gamma Sources

Radiation Processing of Foods------ Vegetables, Fruits and Flowers -----

Sharma/Sainis

One Process :

Multiple Uses

Sprout Inhibition

Onion, Potato, ginger,Garlic

Quarantine

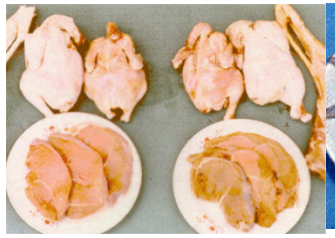
Fruits

Insect Disinfestation

Cereals, Pulses, Dry Fruits

Shelf-life Extension

Chicken, Meat, Fish

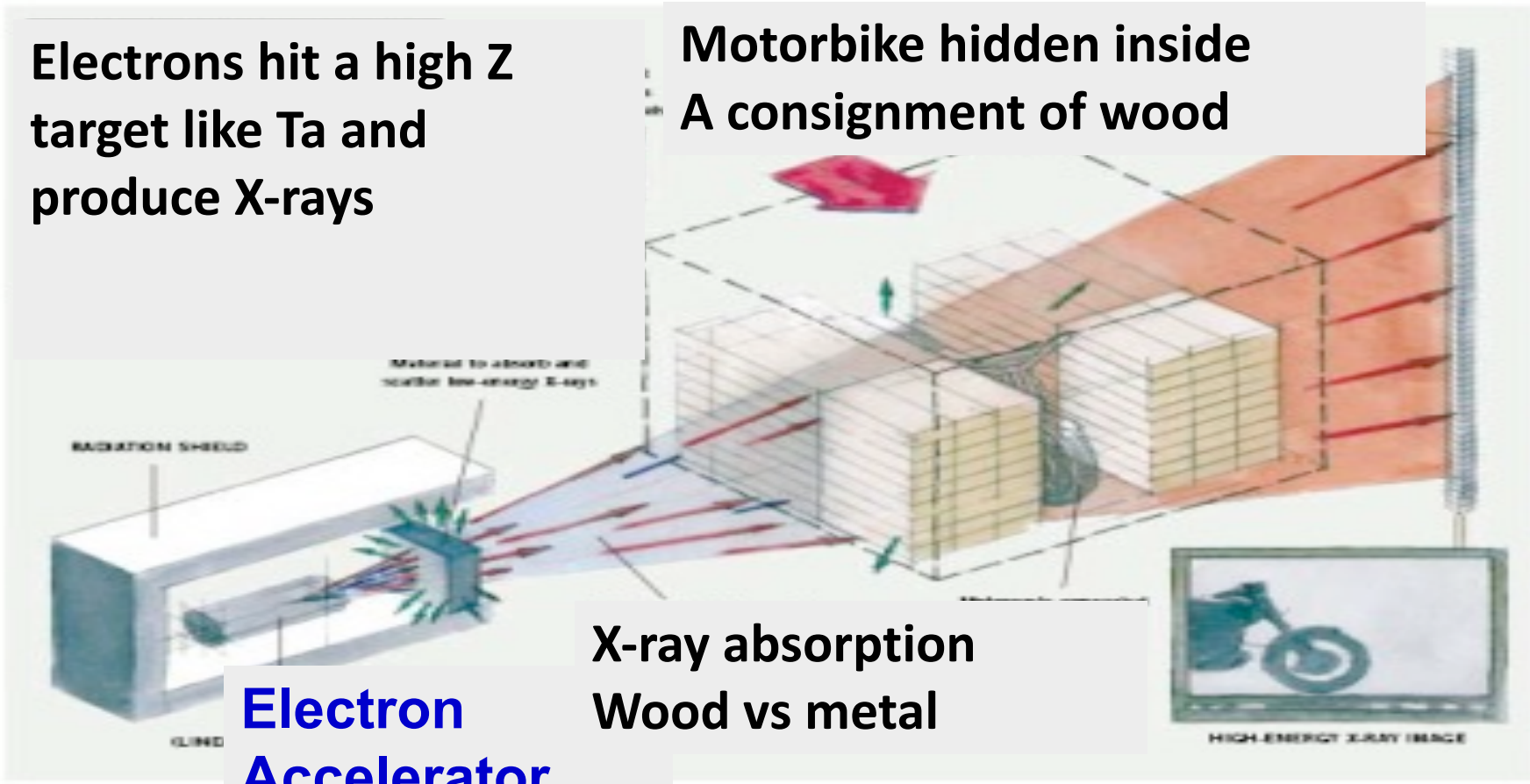


Hygienization

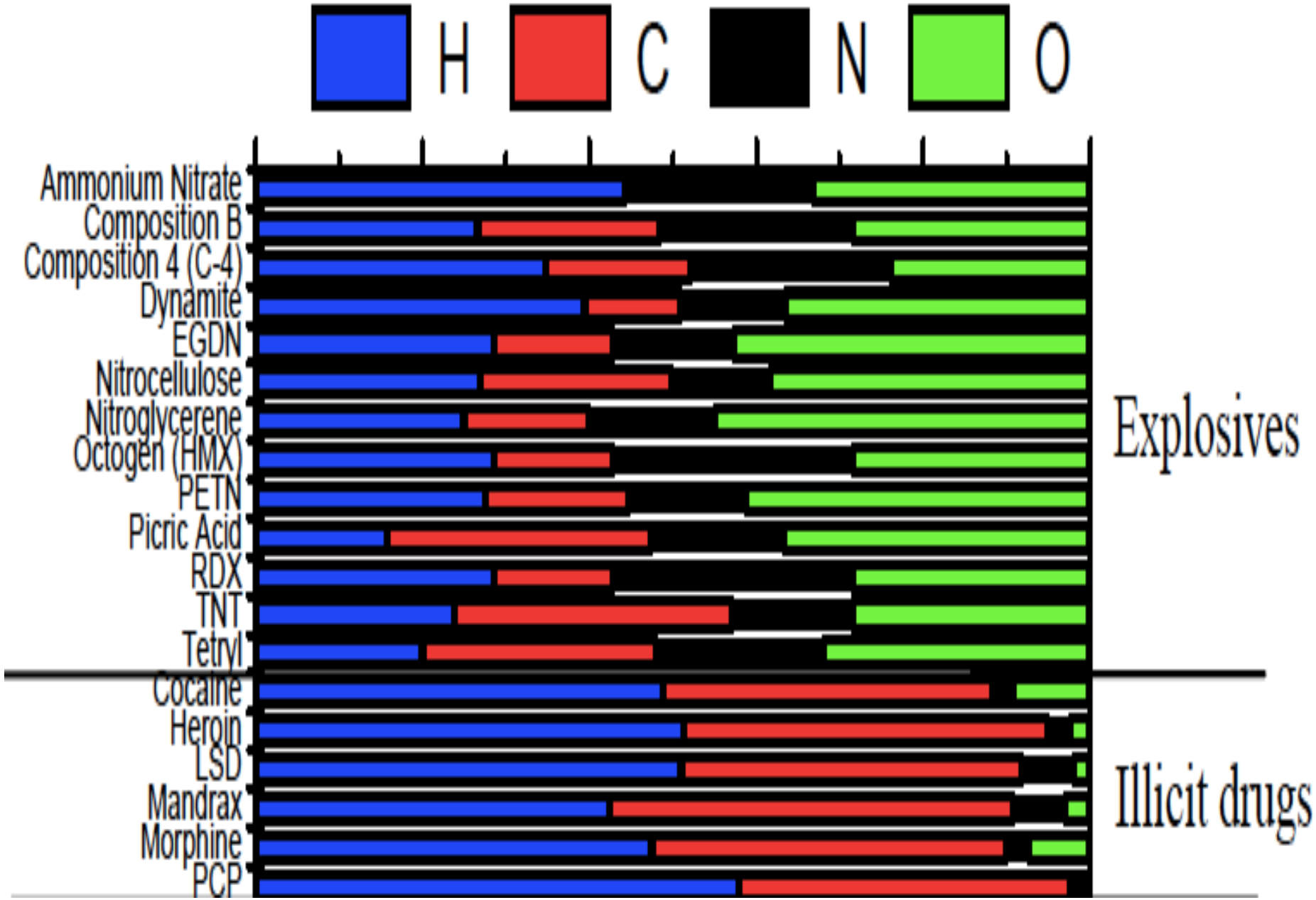
Spices, Flesh Foods

NATIONAL SECURITY

Schematic of cargo scanner based on Electron Accelerator



Courtesy: A.Sinha


H
C
N
O
Ammonium Nitrate
Composition B
Composition 4 (C-4)
Dynamite
EGDN
Nitrocellulose
Nitroglycerene
Octogen (HMX)
PETN
Picric Acid
RDX
TNT
Tetryl
Cocaine
Heroin
LSD
Mandrax
Morphine
PCP
Explosives
Illicit drugs

Explosives, Illicit Drugs

- Different Compositions of the above elements

EXPLOSIVES

Nitro Cellulose - $C_6H_9N_1O_7$

EGDN - $C_2H_4N_2O_6$

RDX - $C_3H_6O_6N_6$

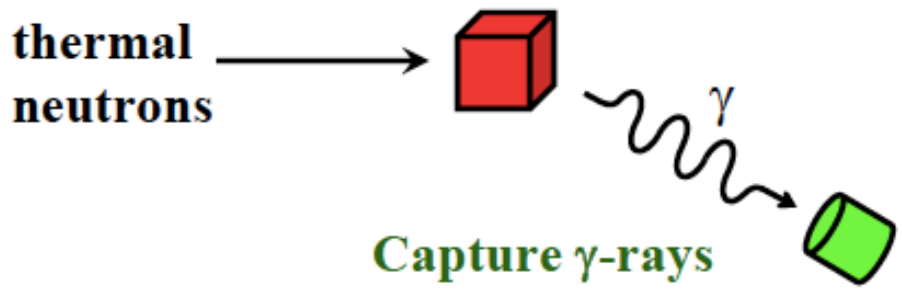
ILLICIT DRUGS

COCAINE - $C_{17}H_{21}N_1O_4$

MORPHINE - $C_{17}H_{19}NO_3$

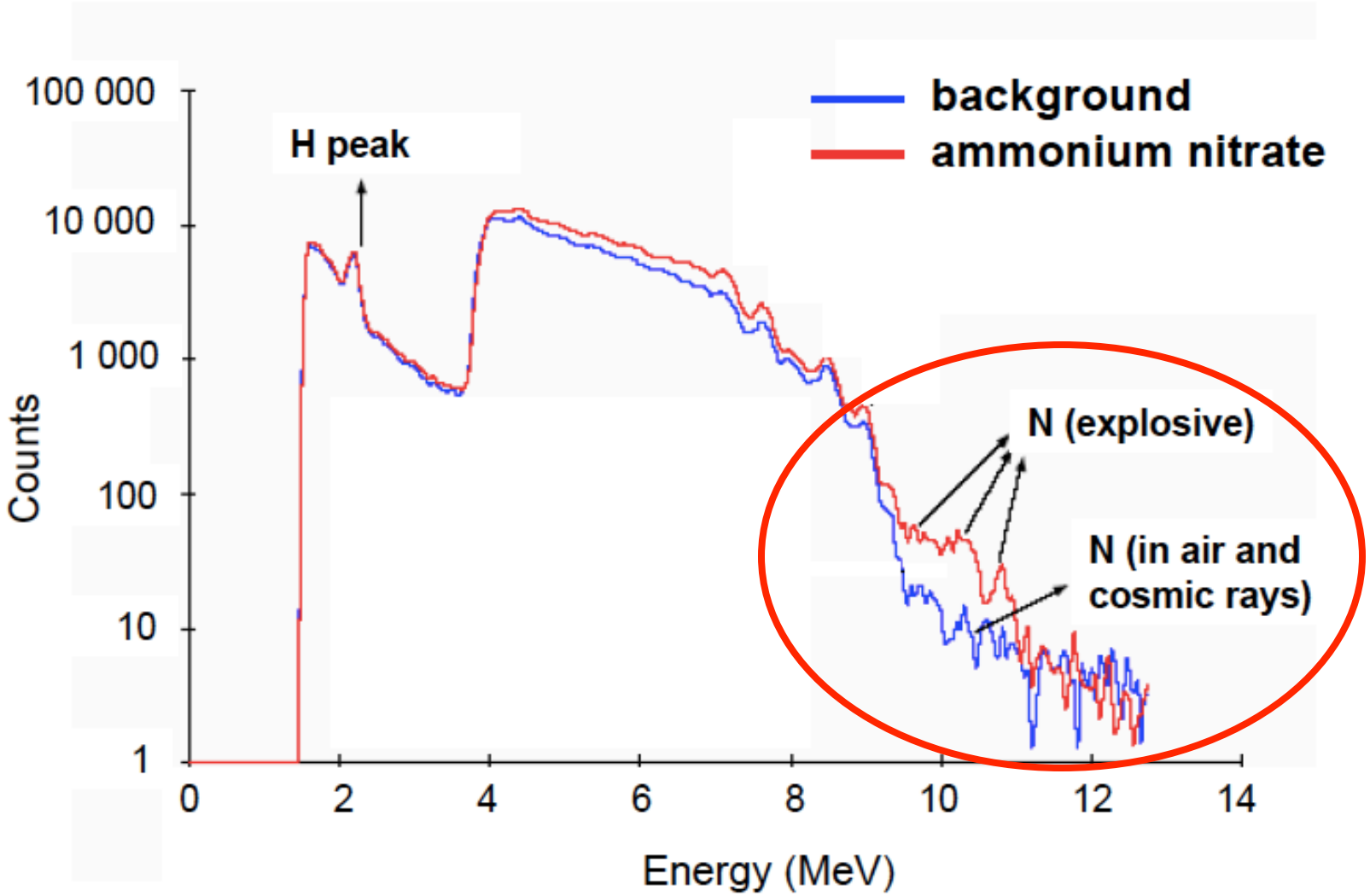
Thermal neutron capture

Neutron Energy 0.025 eV



$$^{14}N + \text{thermal neutron} \rightarrow {}^{15}N + \gamma\ (10.83\ \text{MeV})$$
$$^{1}H + \text{thermal neutron} \rightarrow {}^{2}H + \gamma\ (2.223\ \text{MeV})$$

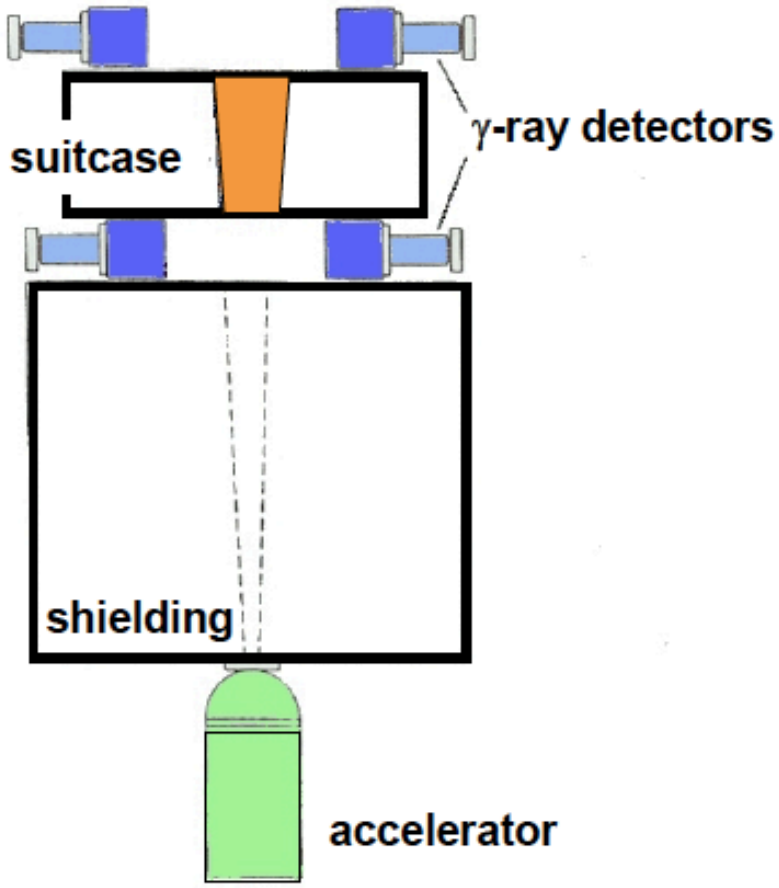
TNA spectrum for a bag with and without a small explosive

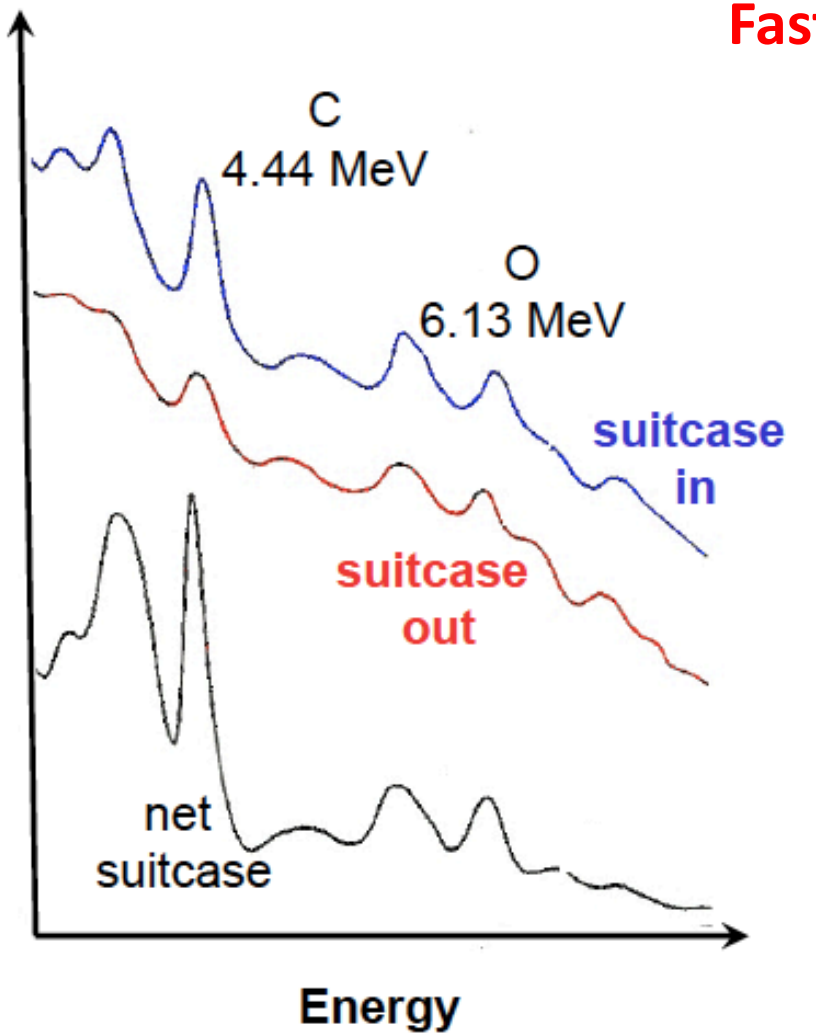


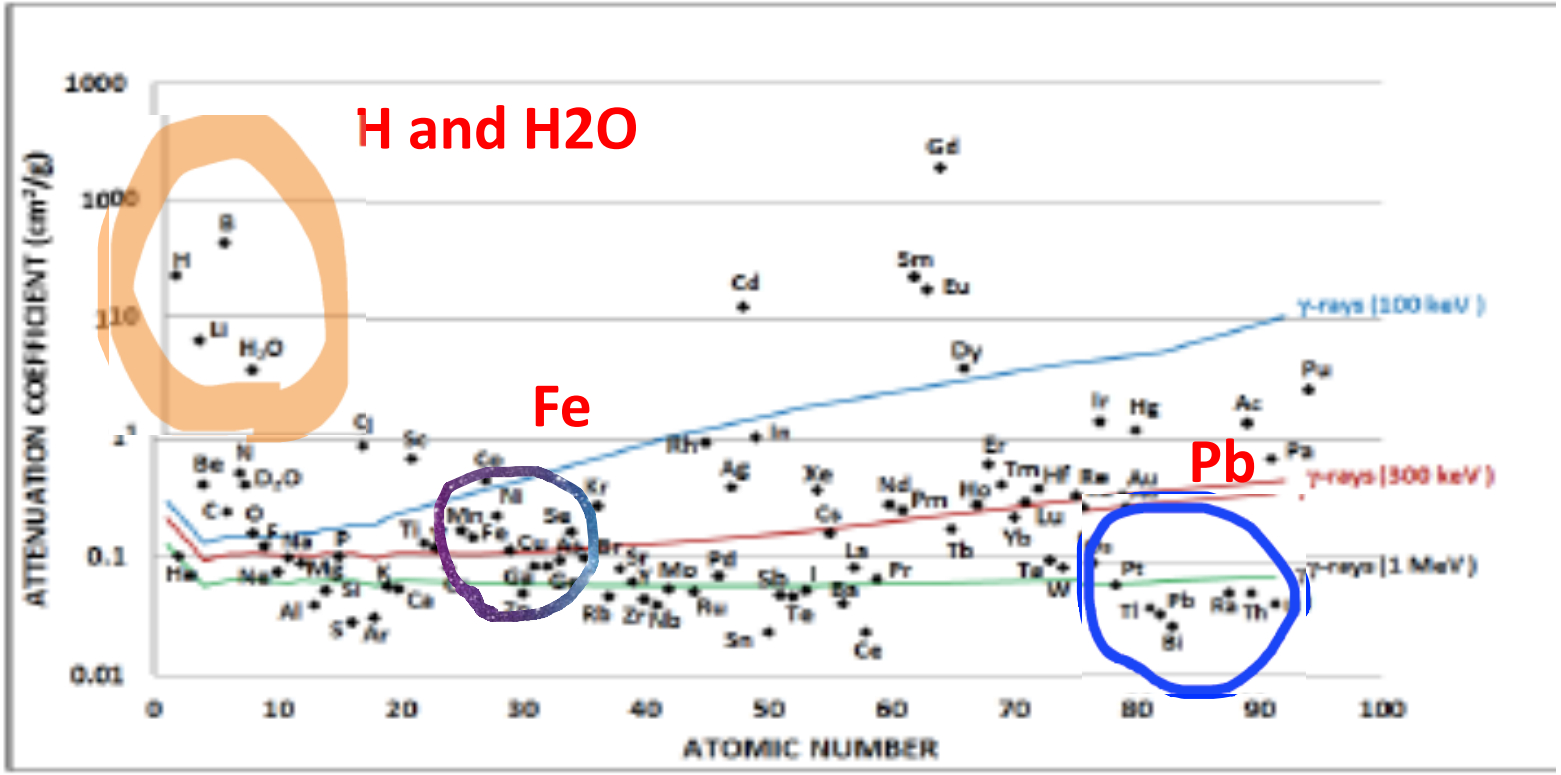
Slow Neutrons

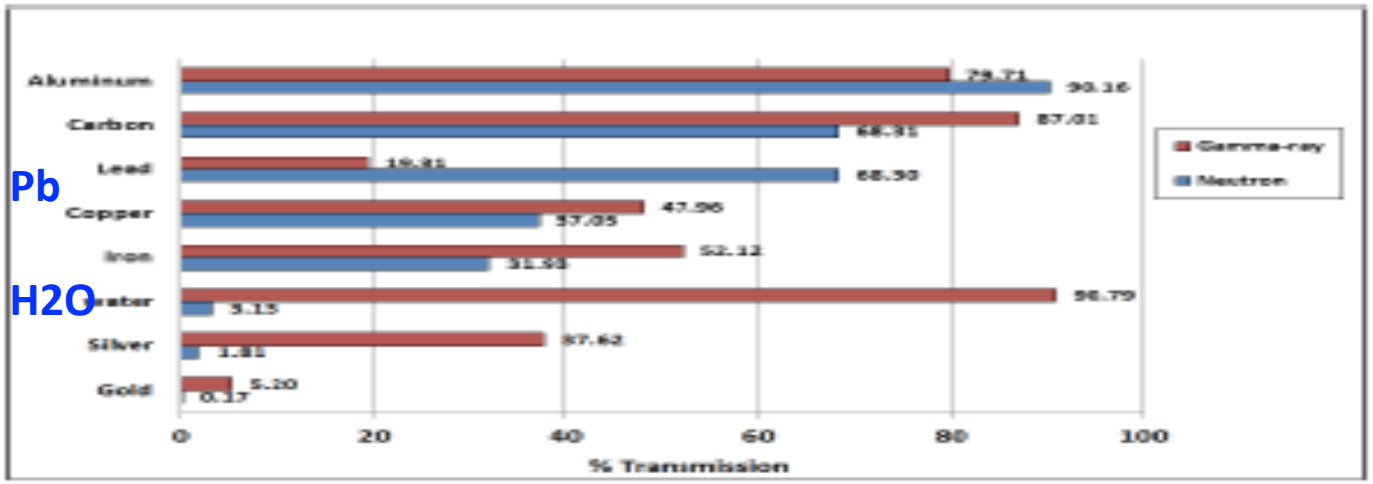
Fast Neutron Inelastic Scattering to detect explosives in luggage

Fast Neutrons









Mass Attenuation coefficient Of Thermal Neutrons

$MAC = \Sigma / \rho$

$\Sigma = 6.0X10^{23} \sigma \rho / A$

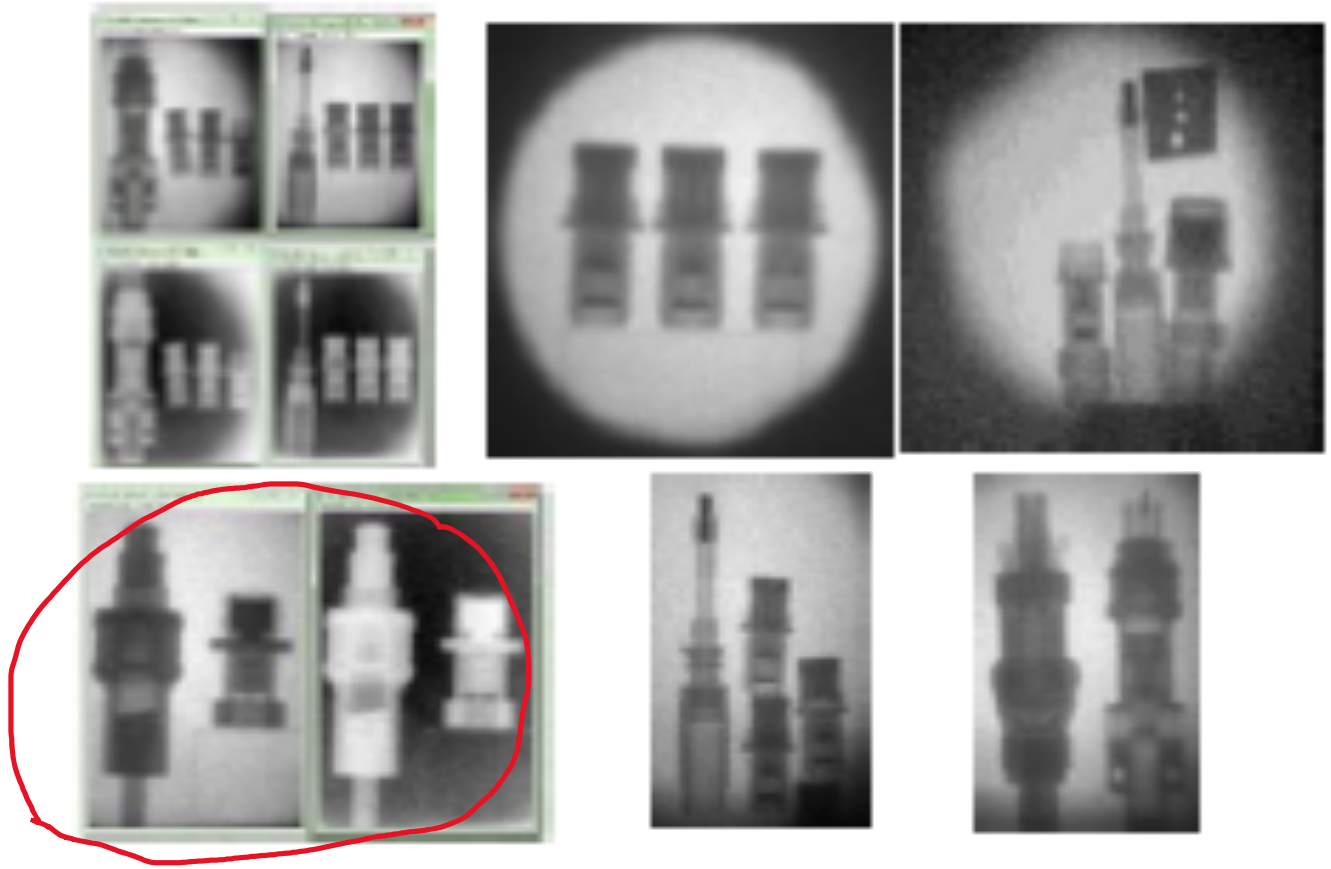
$I = Io \exp(- MAC X \rho x)$

MAC value for H (H2O) are very large compared to Steel and Lead

We can use thermal neutrons to look at H Inside Steel or Lead

DAE – ISRO collaboration
Portable 14 MeV neutron Generator surrounded by Moderator to get thermal Neutrons

NEUTRON IMAGING



Pyrotechnic devices – mg quantity explosive inside SS vessel. Crucial for space programme. How to know the right amount of explosive is present inside SS? Use thermal neutrons significantly more Sensitive to Hydrogen(in explosives) than to the SS vessel.

Courtesy: Dr.A.Sinha

To Sum Up:

- **Nuclear Science and related technologies -Have profound influence on Society-Energy, Health, Industry, Agriculture, Security.....**

- **In the DAE, technologies based on nuclear radiation have been developed and deployed for public.**

- **Training in Nuclear Radiation Science/ allied technologies open up opportunities for a career in nuclear power programme, healthcare facilities, medical instrumentation , semiconductor industry, companies making nuclear instruments and detectors**

Sir C.V.Raman --" Success can come to you by courageous devotion to the task lying in front of you"

References

- *S. Kailas and R. Chidambaram Accelerators for Science and Society Proc. Indian National Science Academy 89A (2019)3*
- *R.K.Bhandari and A. Roy. Current Science 108(2015)1608*
- *D.V.Gopinath and N.Ramamoorthy, Ionising Radiation and Mankind, Cambridge Scholars Publication (2019)*
- *Analytical Aspects of Nuclear Techniques- IAEA (2004)*
- *Accelerators for Science and Technology – IANCAS Bulletin 2006*
- *K.M.Varier, A. Joseph and P.P.Pradymnan,Advanced experimental techniques in modern physics , Pragati Prakashan(2006)*
- *www.accelerators-for-society.org*