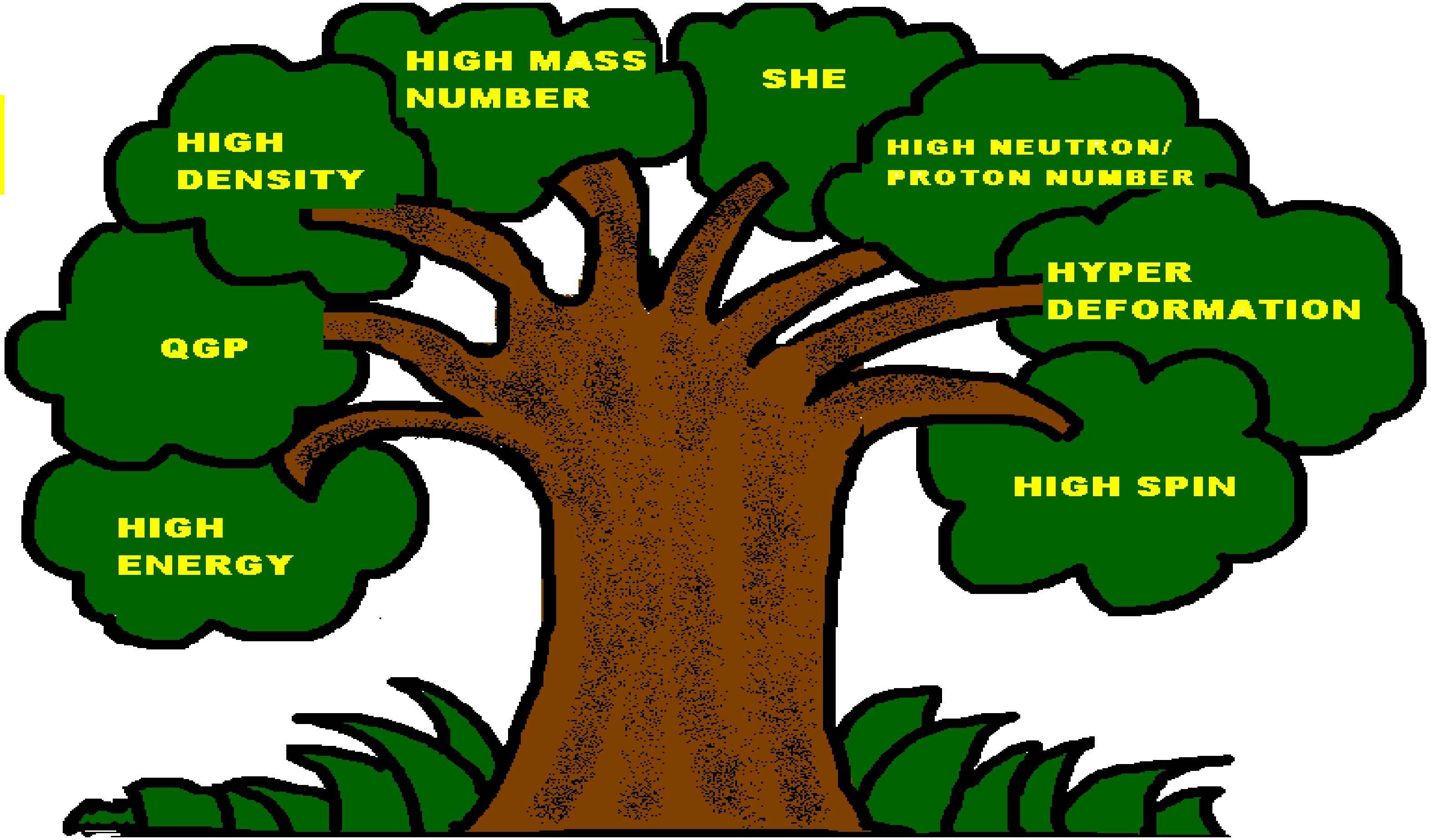
NUCLEAR PHYSICS , SPINOFF TECHNOLOGIES AND IMPACT ON SOCIETY

S.KAILAS

UM and DAE *Centre for Excellence in Basic Sciences, Mumbai*

Growth of Nuclear Physics Research

300 Nuclei



3300 Nuclei

Accelerators

Detectors

Electronics

Computers

Why Charged Particle Accelerator

- Ions from H to U
- Single to multiple charged ions-
- Ion energies from eV to TeV
- Beam intensity -a few ions/cm^2 to 10^{18} ions/ cm^2
- Size of ion beam – cm to nm
- Scan ions over an area – a few sq.cms
- Range of ions – from nm to m
- Secondary particles
- Wavelength $\propto$ is $1/\sqrt{E}$ - investigate nuclei,
- Matter, molecules, atoms..
- Creation of New particles $E = Mc^2$

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

60% are used in Industry

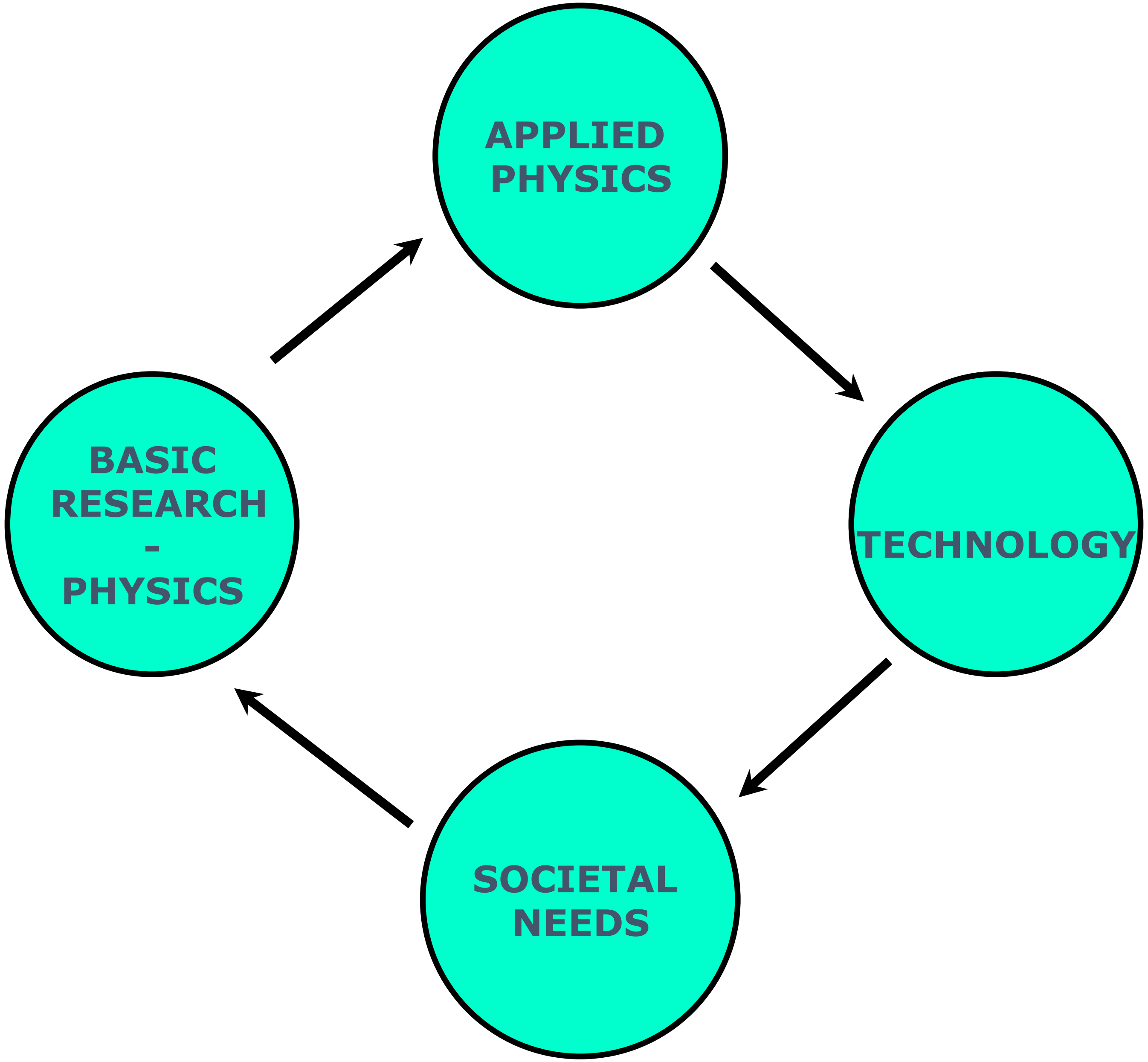
30% in Healthcare

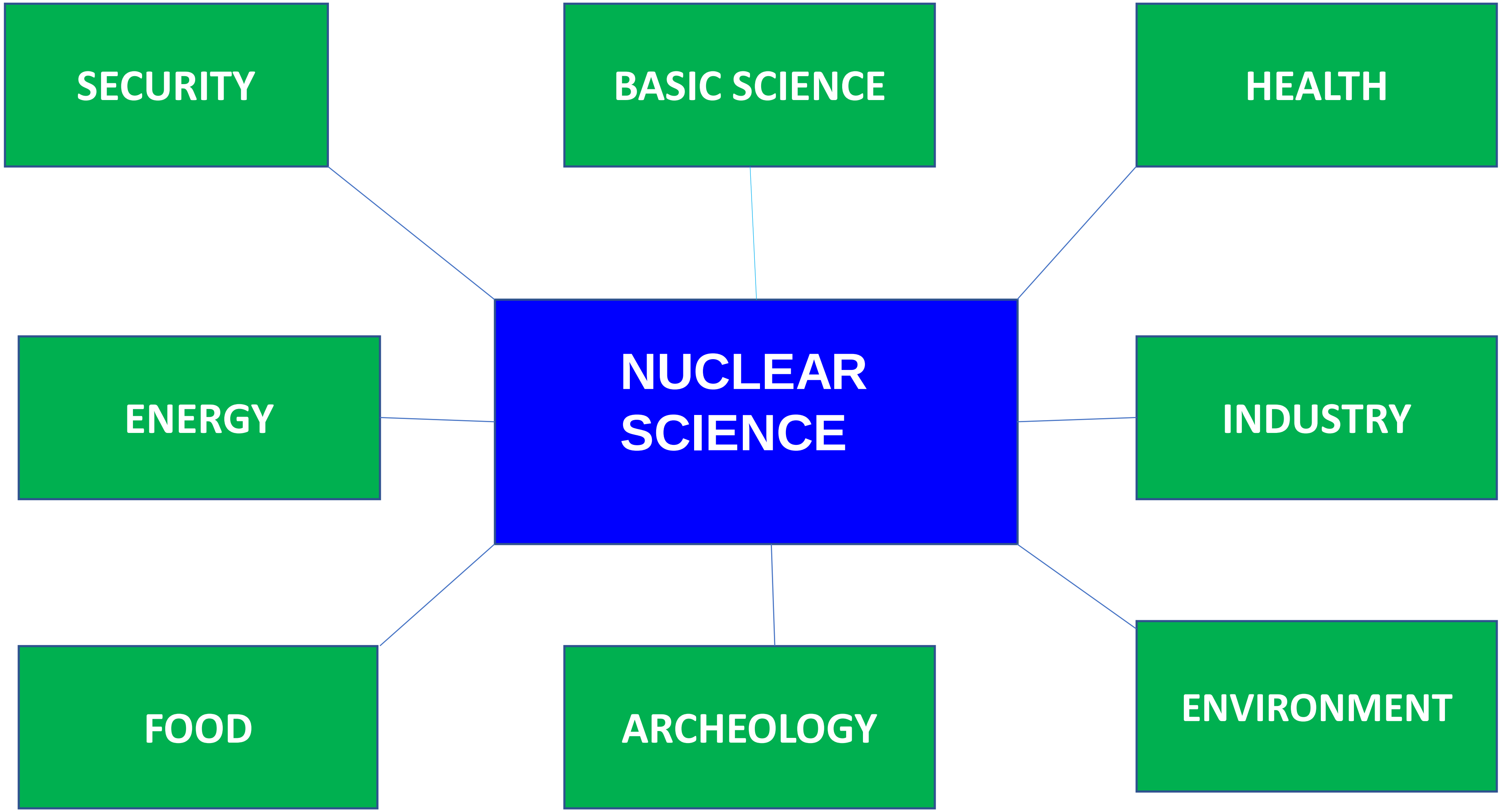
Around 1 % in Basic research

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!

PHYSICS IN SOCIETY




SECURITY
BASIC SCIENCE
HEALTH
ENERGY
NUCLEAR SCIENCE
INDUSTRY
FOOD
ARCHEOLOGY
ENVIRONMENT

Nuclear Physics – Recent Highlights

The Era of Higgs Physics

July 1, 2022 • Physics 15, 98

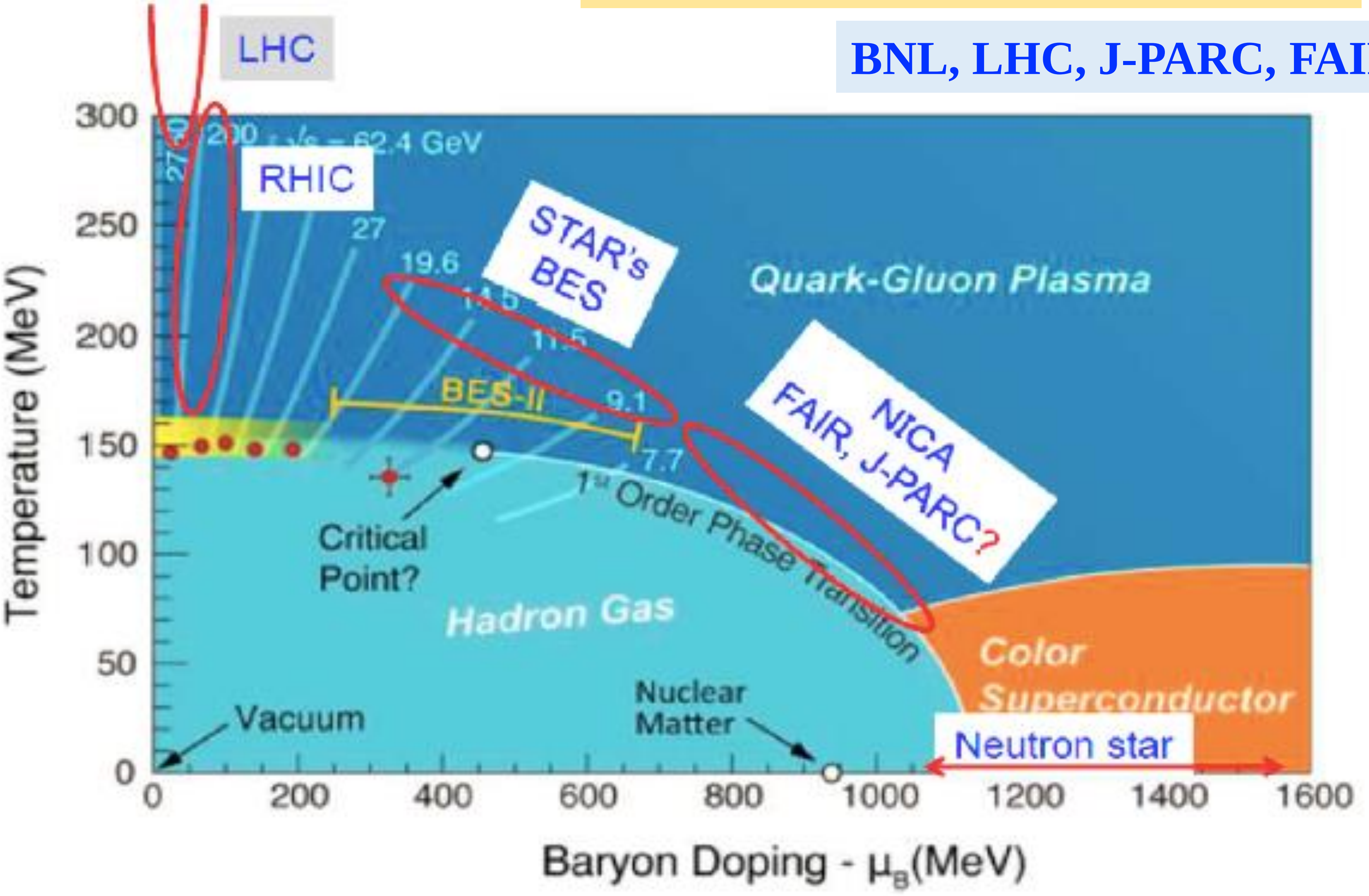
Ten years of Higgs physics have revealed how much more there is to learn about the mysterious particle.

Ten years after its discovery, the Higgs may have disappointed some with its adherence to the standard model. But its apparent conformity has proven useful, and its remaining secrets continue to inspire particle physicists.

S. Nagamiya Entropy 24,482 (2022)

High ENERGY DENSITY Nuclear Matter

BNL, LHC, J-PARC, FAIR, NICA



Shape of Atomic Nuclei in High Energy Heavy Ion Collisions

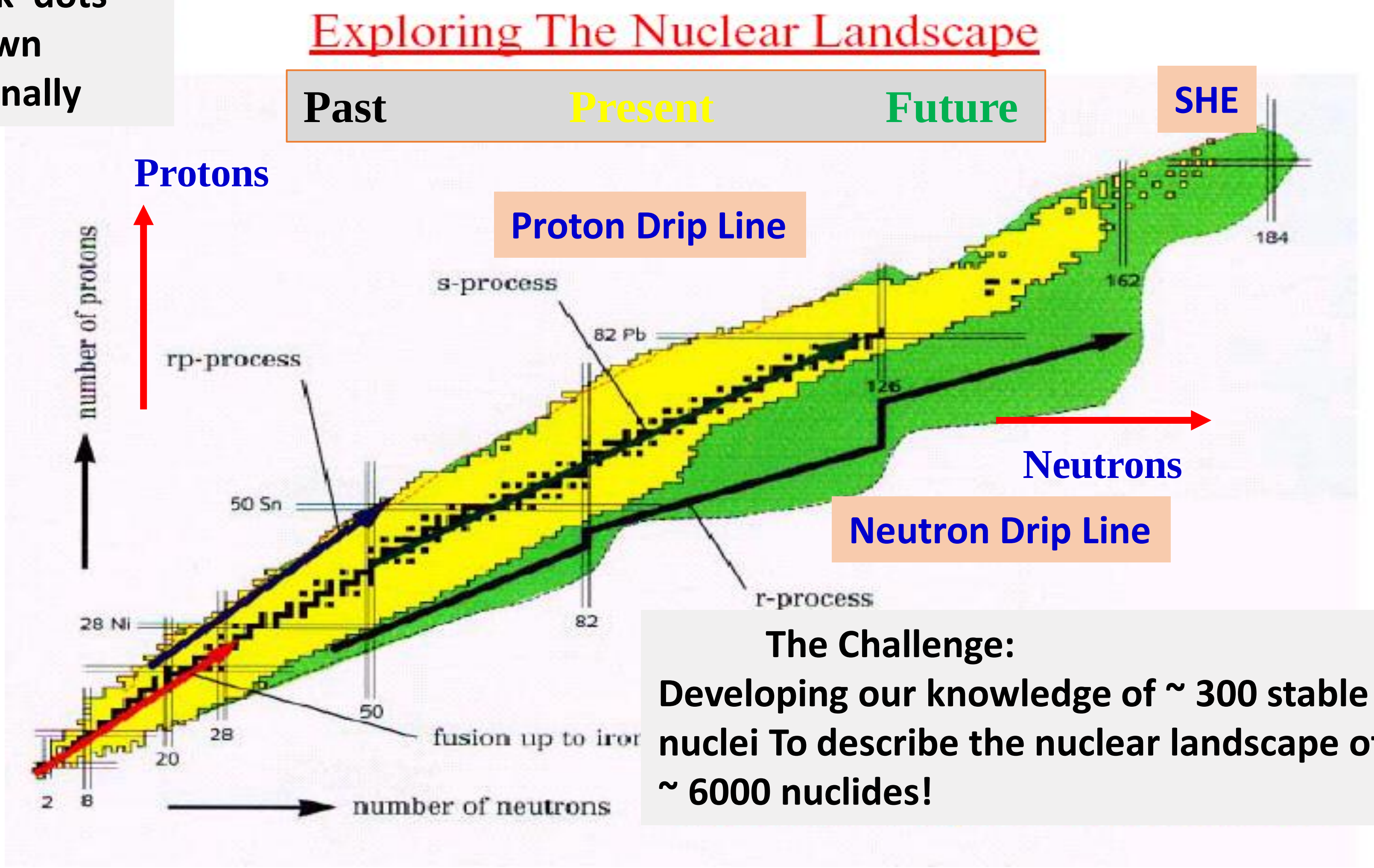
J. Jia (2021) https://arxiv.org/abs/2106.08768

In the hydrodynamic model description of heavy ion collisions, the final-state anisotropic flow is linearly related to the strength of the multi-pole shape of the distribution of nucleons in the transverse plane

This opens up the possibility to map the shape of the atomic nuclei at a timescale (< 10−24s) much shorter than probed by low-energy nuclear structure physics (< 10−21s)

Growth of Nuclear Physics

Black dots- Known originally

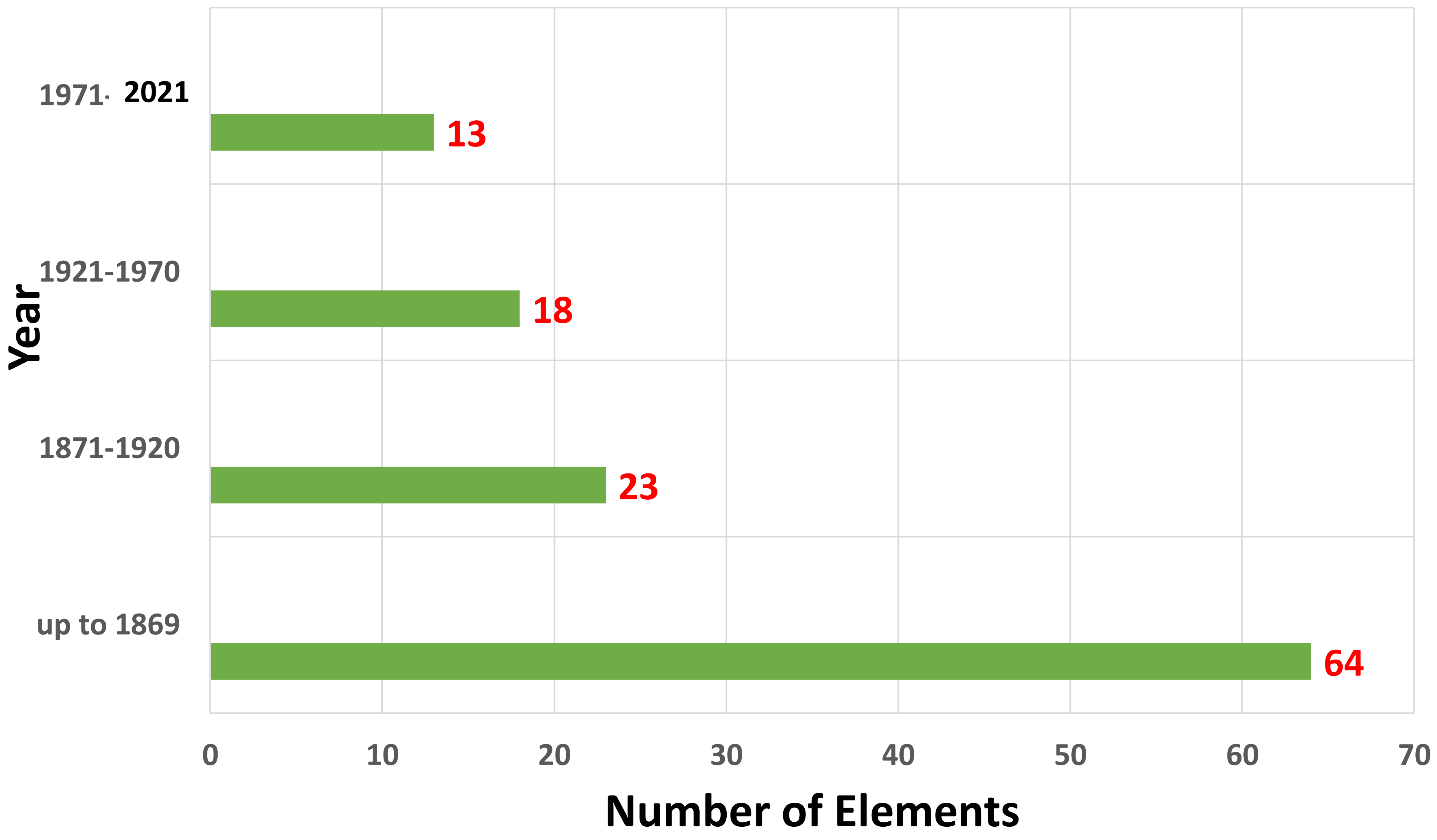


Proton Number

The Challenge:
Developing our knowledge of ~ 300 stable nuclei To describe the nuclear landscape of ~ 6000 nuclides!

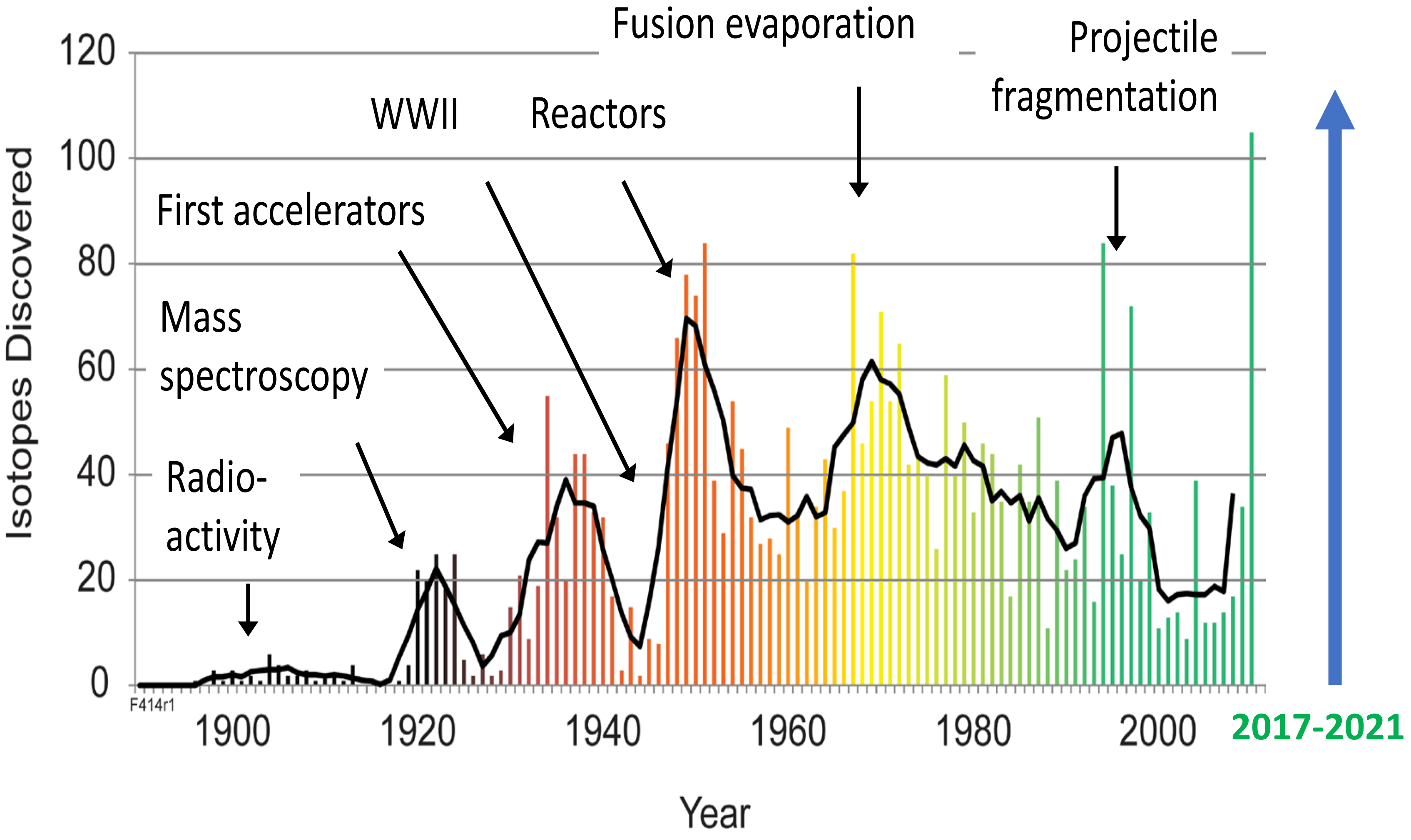
Neutron Number

Time Line for Discovery of Elements



Time Line for Discovery of Isotopes

18Mg decaying by 4 protons detected



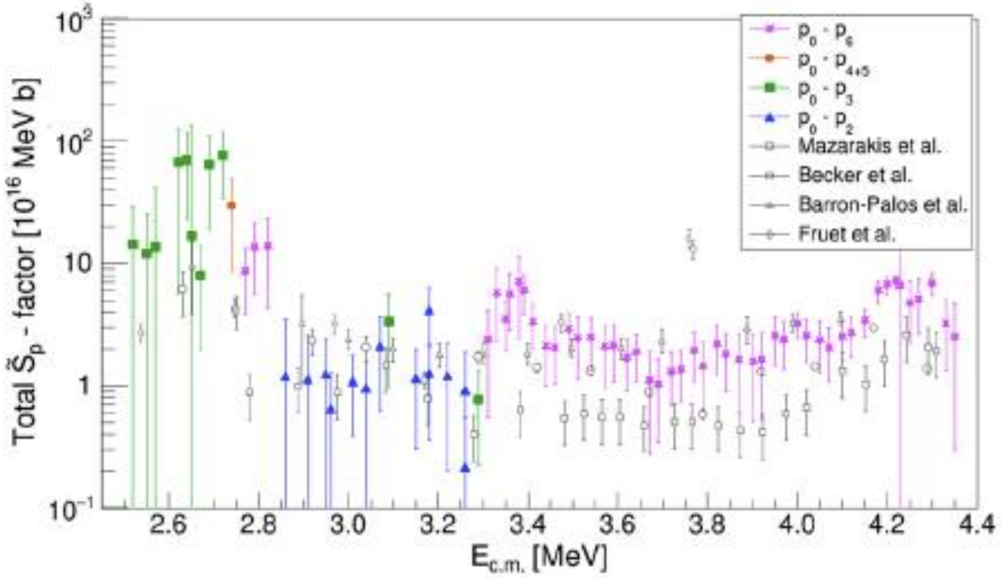
2017-2021	108
2016	12
2015	12
2014	6
Current	3326

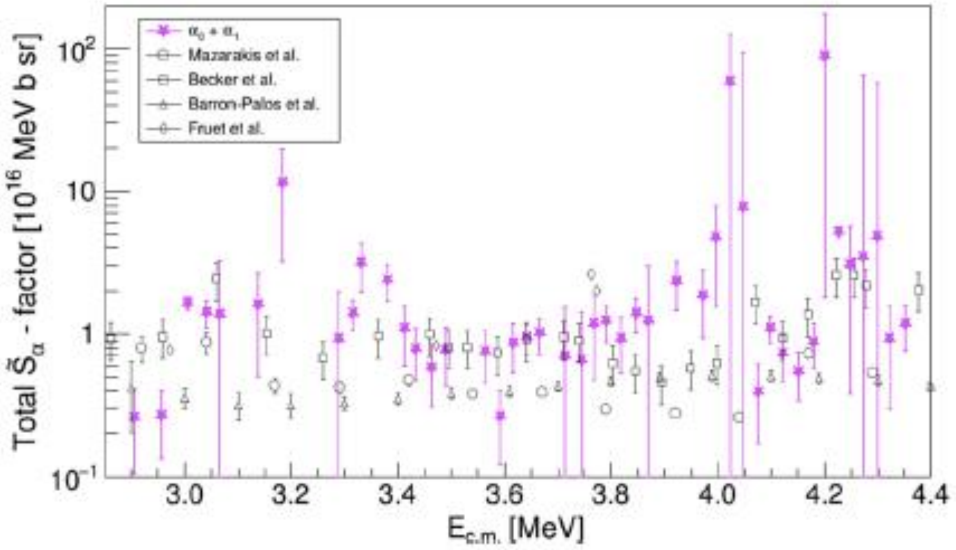
Thoennessen and Sherril,2011

Good News – FRIB commissioned in USA

Direct measurements of the $^{12}C+^{12}C$ reactions cross-sections towards astrophysical energies

Eur. Phys. J. A (2022) 58:65



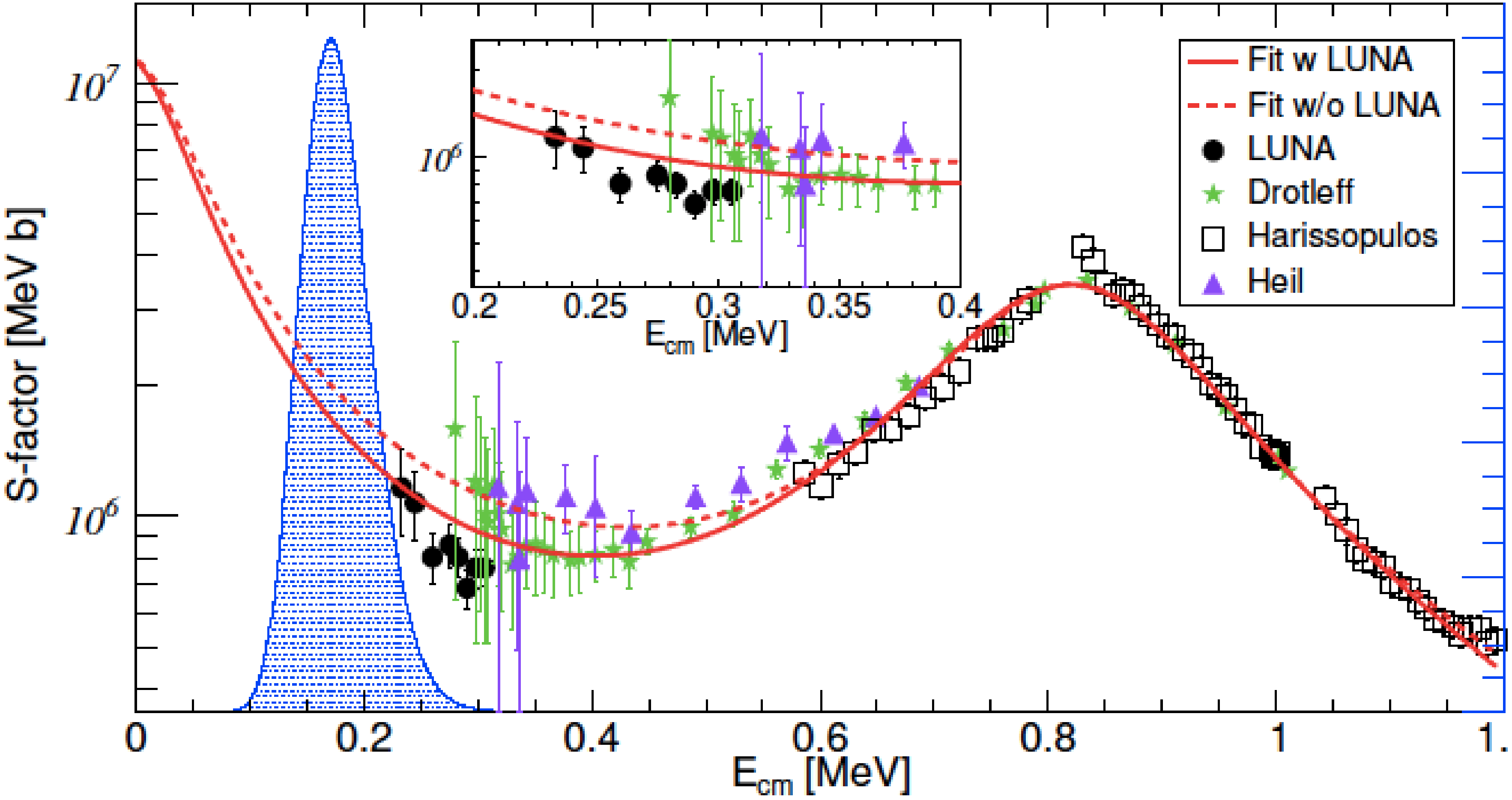


Continues to be interesting and challenging for the Past 50 years

13C(alpha, n) Important Neutron Source for slow neutron capture synthesis

Ealpha in the range 230 to 300 keV close to Gamow peak

LUNA400 Expt (Italy)



Better Precision Measurement.

New measurement of cross section influences sizably the yields of 60Fe, 152Gd and 205Pb in particular PRL 127 , 152701 (2021)

ENERGY

Yesterday's Science. Today' s Technology

Nuclear Fission and Fusion Reactions

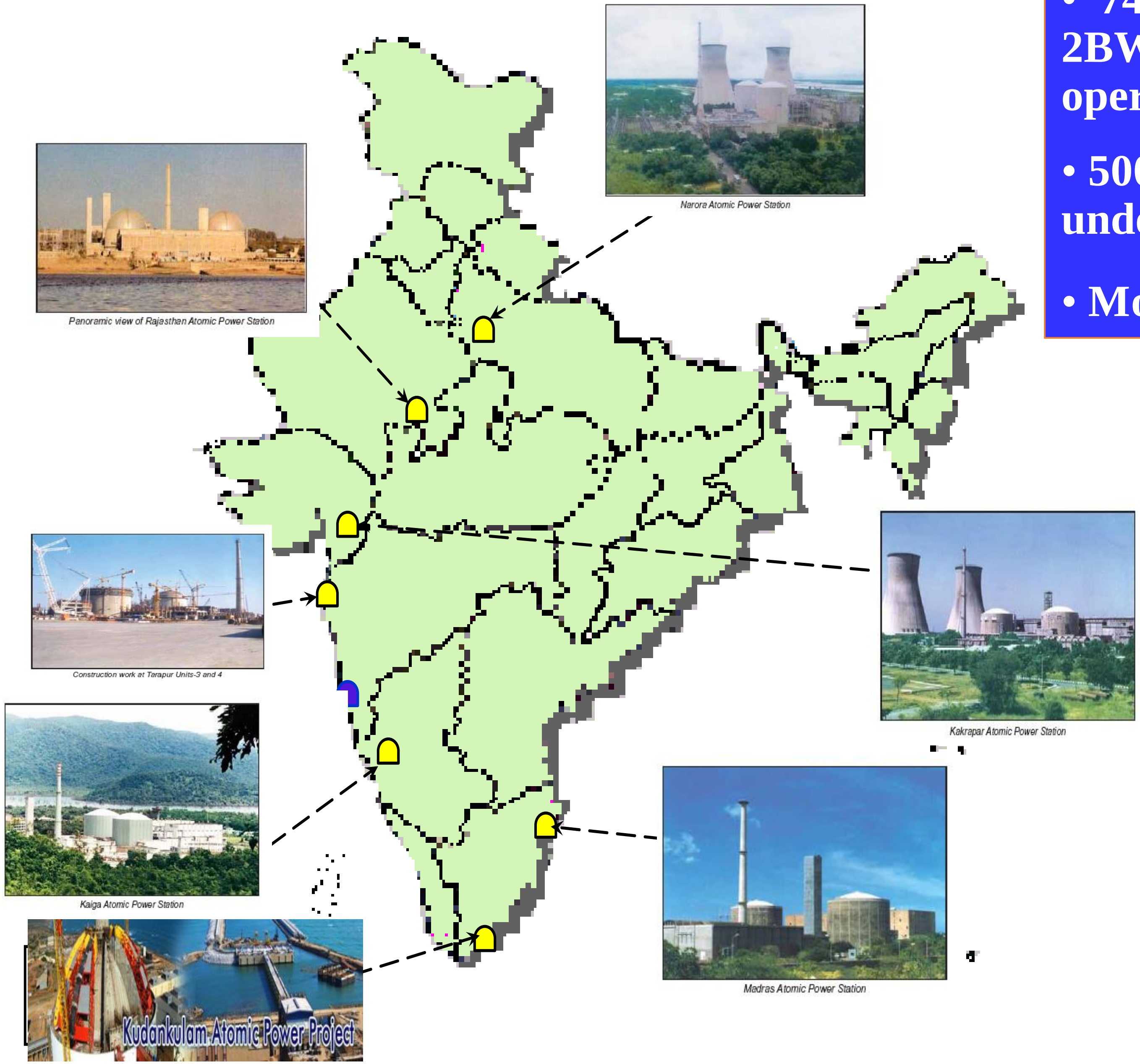
Basic Research - the heart of Nuclear Power

Nuclear Power Programme

Becquerel	(1898)	Radioactivity
Einstein	(1905)	Special Theory of Relativity
Rutherford	(1911)	Nucleus
Chadwick	(1932)	Neutron
Hahn & Strassmann	(1939)	Nuclear fission
Bethe	(1939)	Nuclear Fusion in the Sun

Nuclear power plants in India

- 7480 MW (19 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

ENERGY

Nuclear Reactors nearly 450 -generating power in the world.
Around 50 under construction. India has 23 operational reactors.

Nuclear energy contributes to nearly 10% of total electricity
But contributes to 30% of low carbon electricity in the world

Nuclear complements other renewables like wind and solar.

Nuclear energy will continue to be important in the energy mix
To achieve 1.5 deg temperature rise to be achieved by 2050.

HEALTHCARE

HEALTHCARE

Radio-isotopes through Nuclear Reactions

Reactor produced isotopes – 60Co,131I, 99mTc
Accelerator produced isotopes – 18F, 201Tl,123I

Used for Diagnosis and Treatment

Image organs and also determine the functioning
Of Brain and Heart,

Image Blood flow, Glucose uptake, Oxygen consumption

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

Medical Cyclotron

TMH/ RMC, Mumbai

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

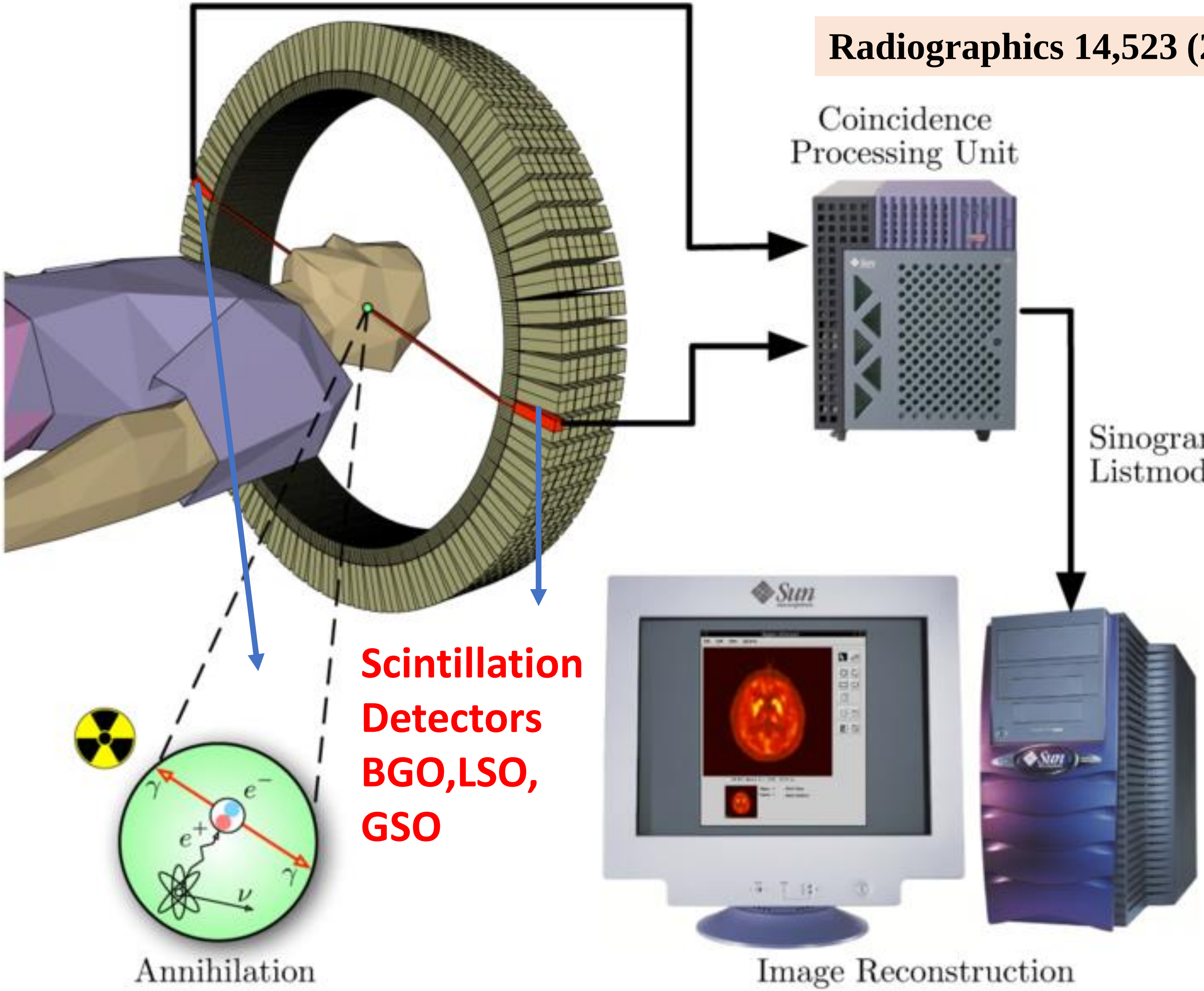
- Radionuclides that can be Produced
- 18F, 11C, 13N & 15O

Some years ago
60 PET – CT in India
30 more planned

30 MeV Medical Cyclotron at Kolkatta

200 MeV
Medical Synchrotron
At Chennai
For Cancer Therapy

200 MeV
Medial Synchrotron
At TMH
Coming up



Radiographics 14,523 (2004)

bismuth germanate
$Bi_4Ge_3O_{12}$ (BGO

High Zeff

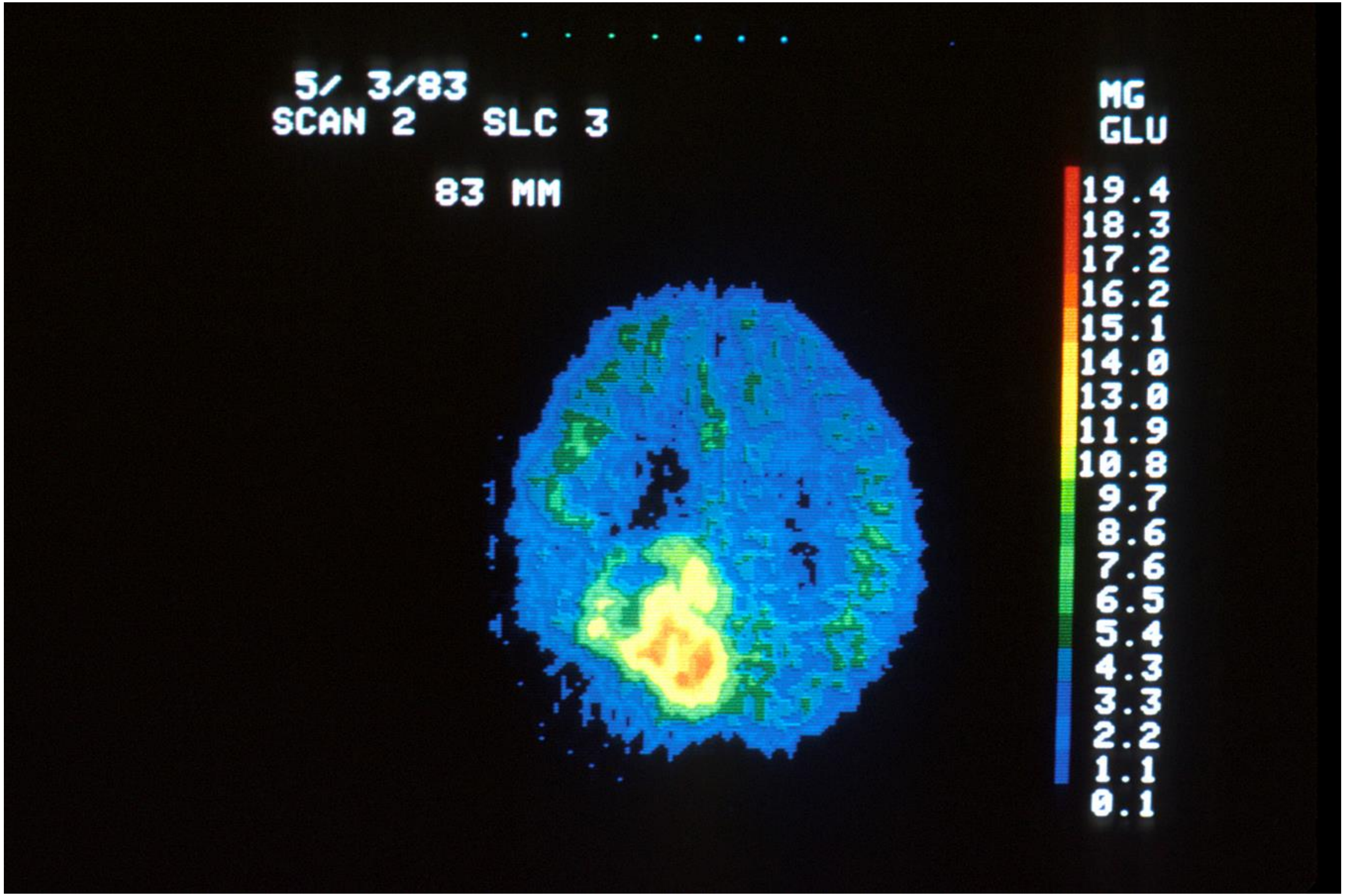
lutetium oxyorthosilicate
doped with cerium
Lu_2SiO_5:Ce (LSO)

Light output,

gadolinium oxyorthosilicate
doped with cerium
Gd_2SiO_5: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

INDUSTRY

Industrial Applications

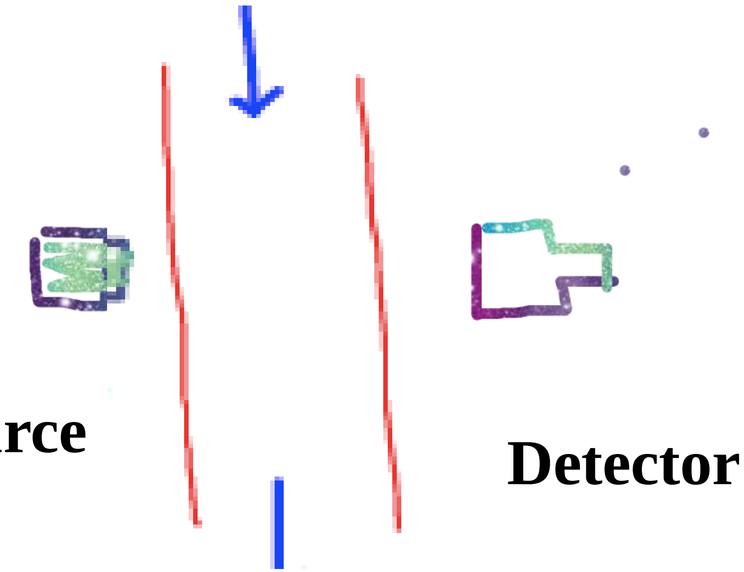
- Ion Implantation – digital electronics
- Electron Beam based materials processing
- Radioisotopes in process industry
- Ion beam analysis of materials
- High energy X-ray inspection of cargo
- Portable Neutron generators for space programme
- Synchrotron radiation for applications
- Production of TEM- Microporous filters –separation science
- Flue gas treatment with electron beam to get rid of NO_2 and SO_2
- ACCELERATOR MASS SPECTROMETRY- Multidisciplinary

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

Nuclear Data in Industry

NUCLEAR TECHNIQUES

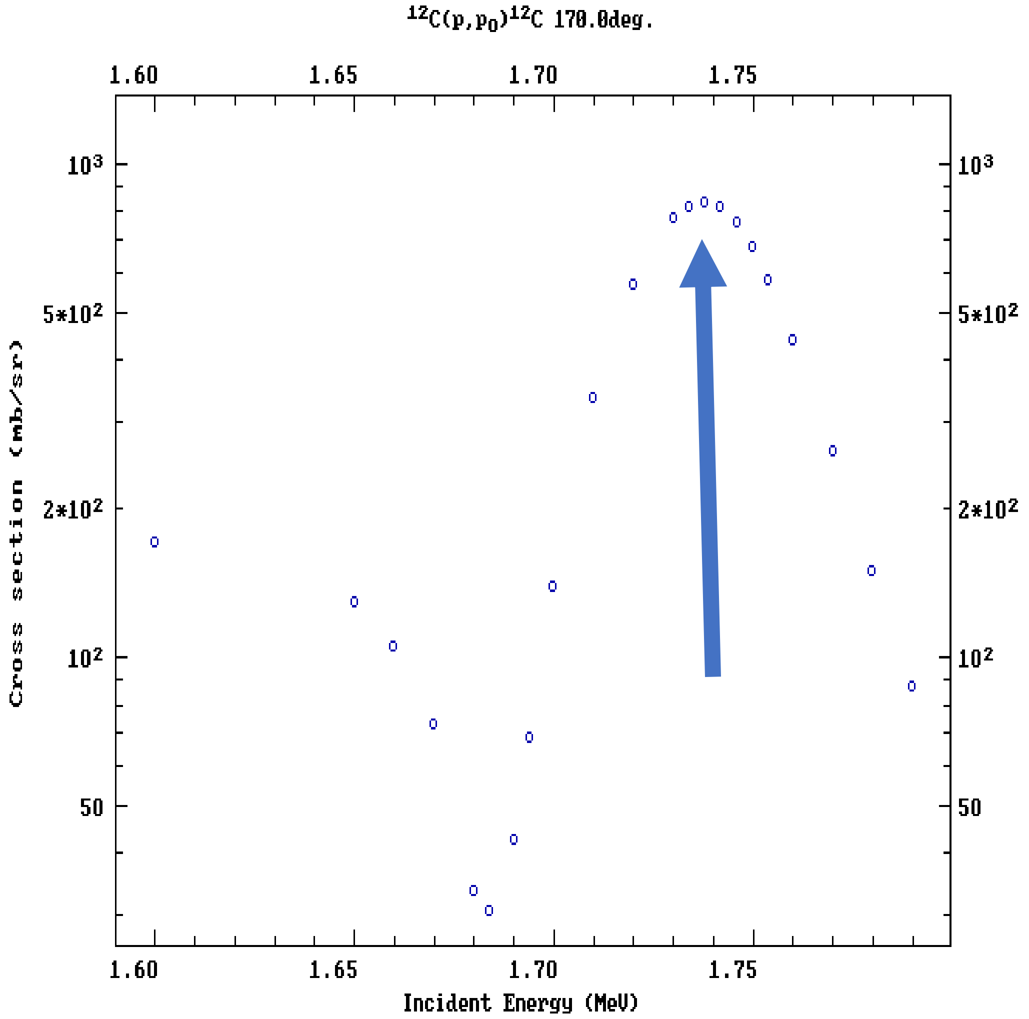
- Elastic Recoil Detection (ERD)
- Nuclear Resonance Analysis (NRA)
- Prompt Gamma Activation Analysis(PIGE)
- Neutron/charged particle Activation Analysis(NAA/CPAA)

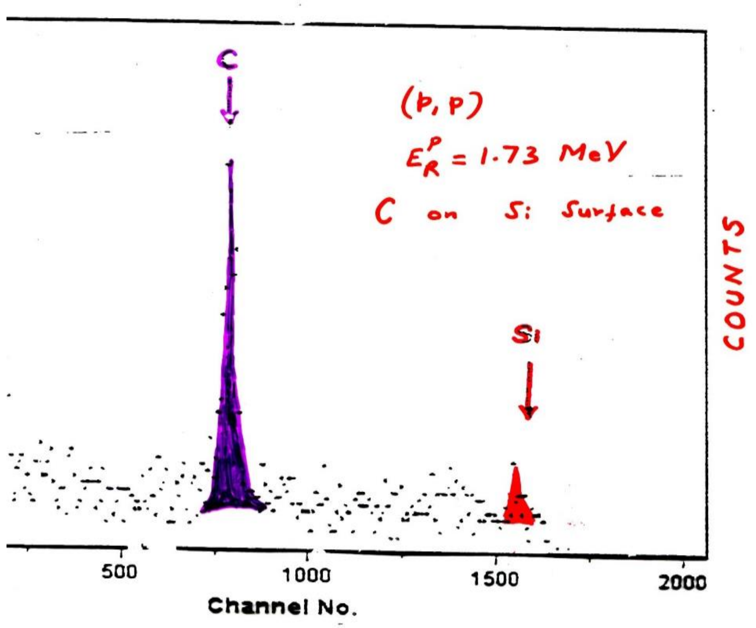
EMPLOYED IN

- Characterisation of Materials / Surfaces
- Trace Level Impurities – detection and quantification
- Composition of Compounds- elemental identification
- Monitoring -wearing of material surface

Use of 12C(p,p) Nuclear Resonance in Material Analysis

Trace level Carbon in Silicon Matrix





ARCHAEOLOGY

Accelerator Mass Spectrometer(AMS)

STABLE ISOTOPES OF VERY LOW ABUNDANCE

AND

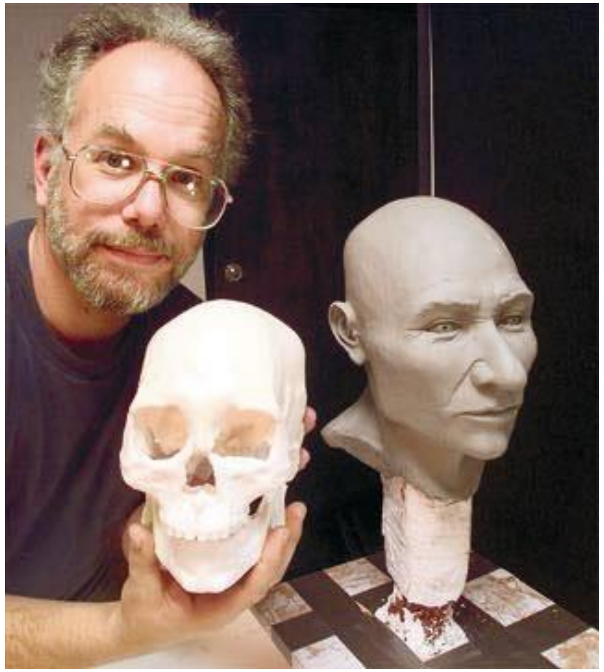
LONG LIVED RADIOACTIVE ATOMS IN LOW CONCENTRATIONS

NEARLY 100 AMS FACILITIES

PROGRAMMES

Geology, Archeaology, Hydrology, Climate, Medical…….

Famous Artifact Radiocarbon Dated
Half life of 14C is around 5730 yrs

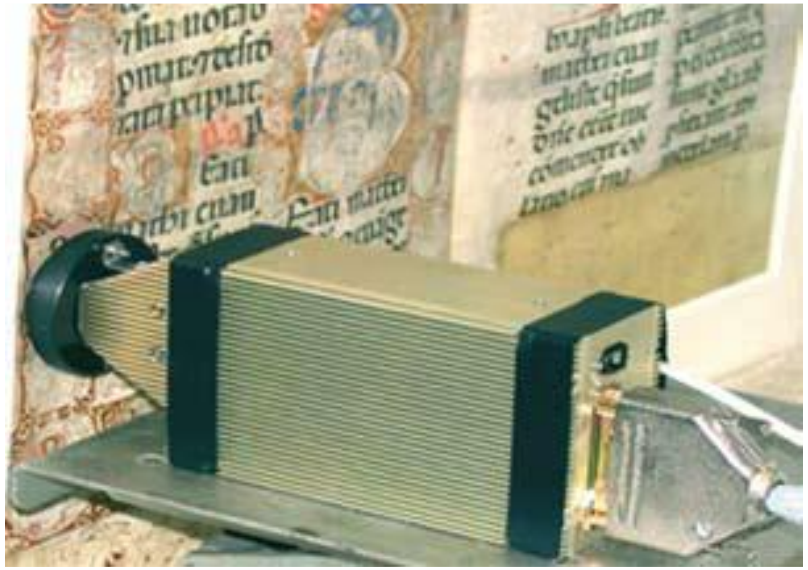


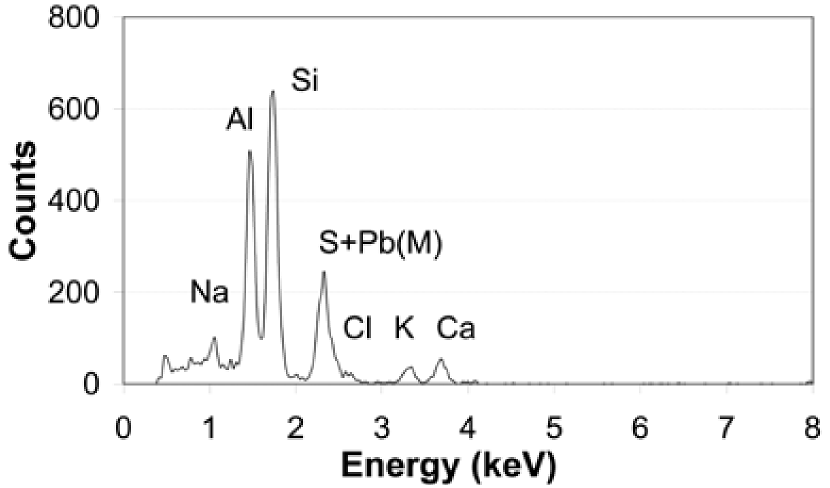
Ratio 14C/12C is a measure
Of the age of the sample
14C is radioactive and 12C
Is stable

Kennewick Man

- Found in July 1996
- Almost immediately controversial
- Who owns? Indian tribes? Local officials? Scientists?
- Bone dated - 9,000 years old!
- Clearly pre-Columbian

Pigments/elements used In Ancient paintings





Portable PIXE(alpha)

AGLAE in France
(located in a museum)

LABEC in Italy

Small Accelerators
Dedicated to this activity

Using PIXE/PIGE

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

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

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
- Nuclear Radiation can be used to Extend the Shelf Life

- Insect can be disinfected
- Eliminate Food Borne pathogens and parasites

- Delay in Ripening of Fruits
- Inhibition of Sprouting

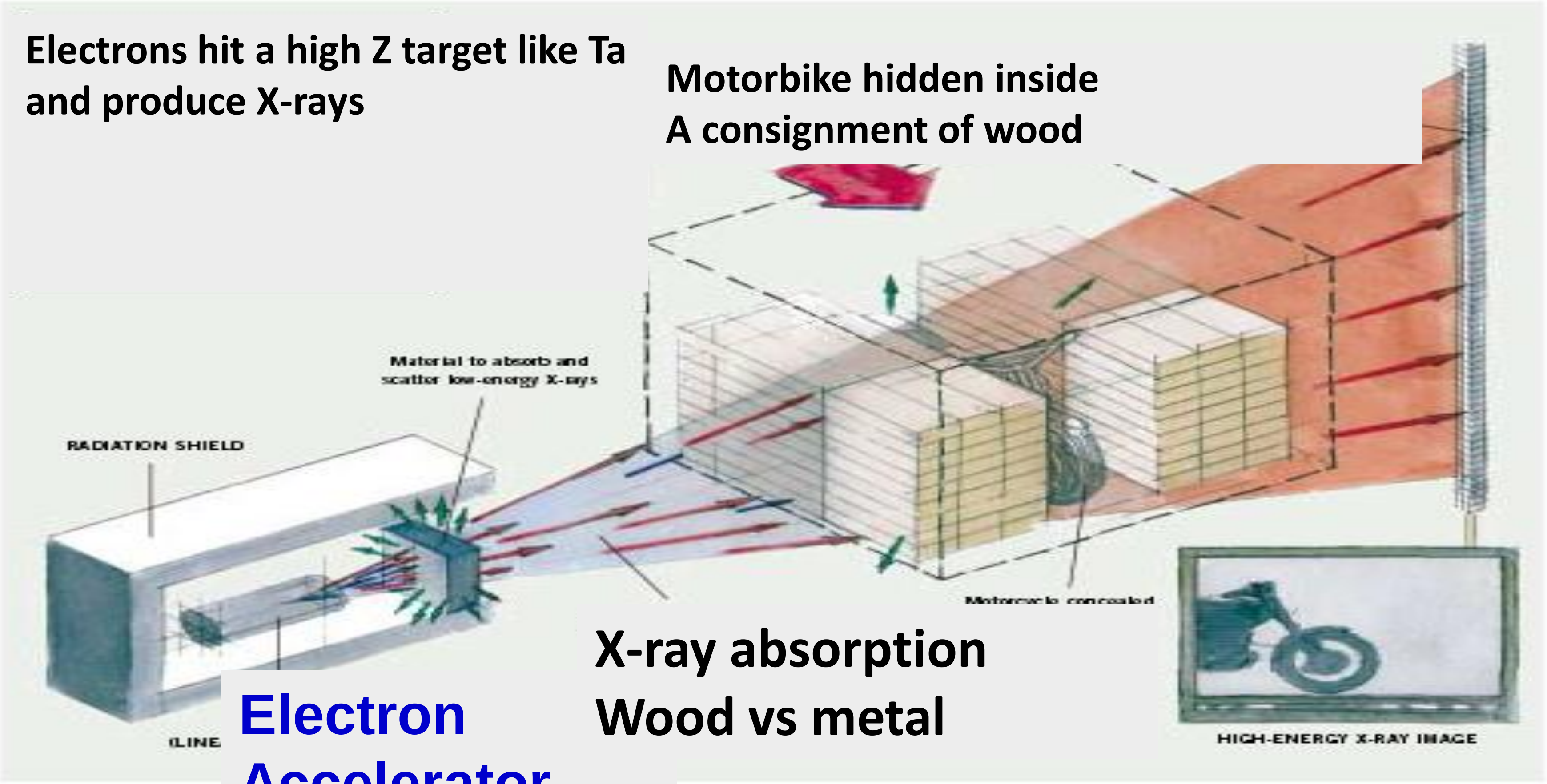
- 16 Gamma Irradiation Plants operational
- We have electron accelerator at Indore developed
- By RRCAT for irradiation of agricultural products

NATIONAL SECURITY

Schematic of cargo scanner based on Electron Accelerator

Electrons hit a high Z target like Ta and produce X-rays

Motorbike hidden inside
A consignment of wood

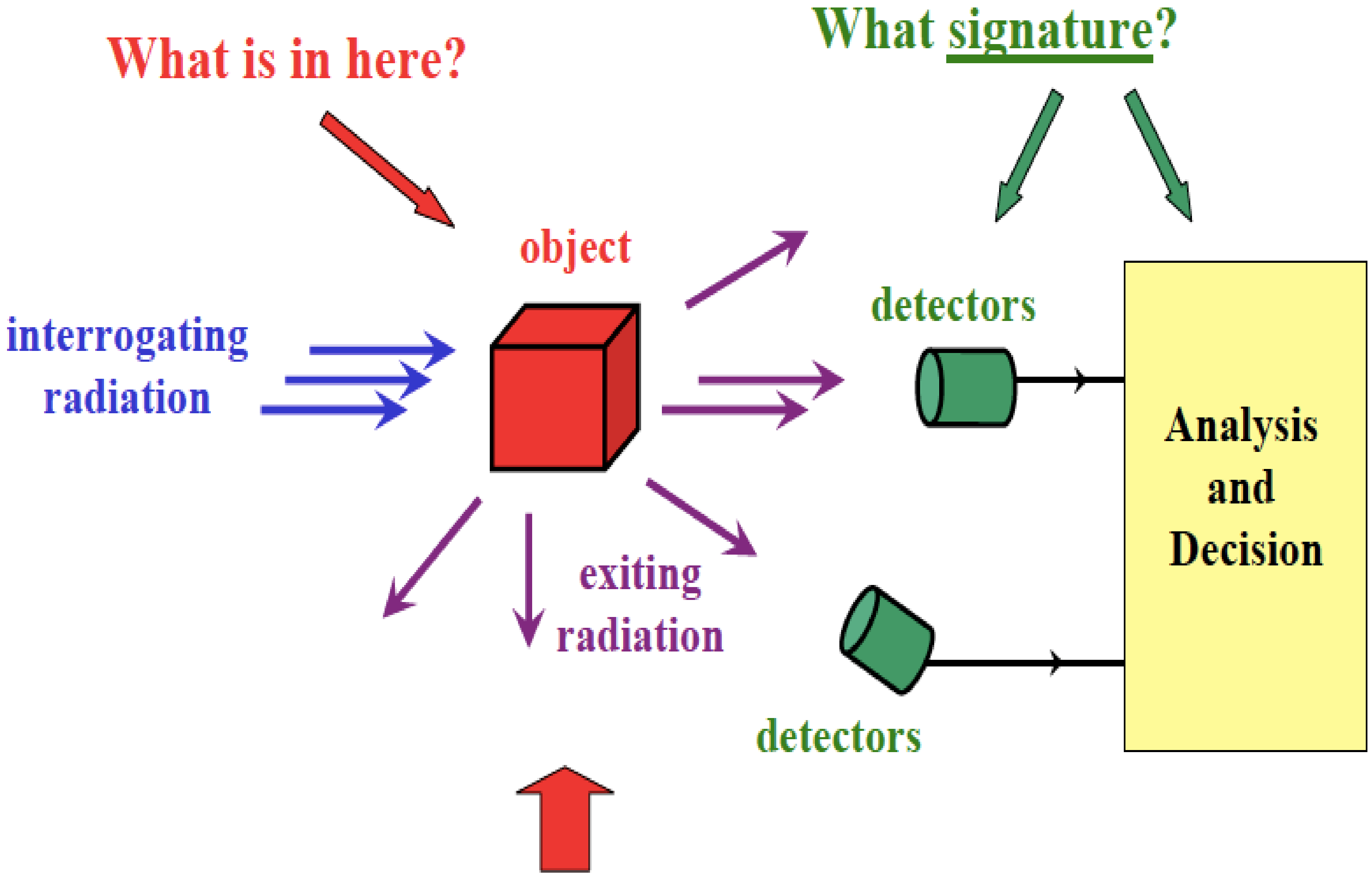


X-ray absorption
Wood vs metal

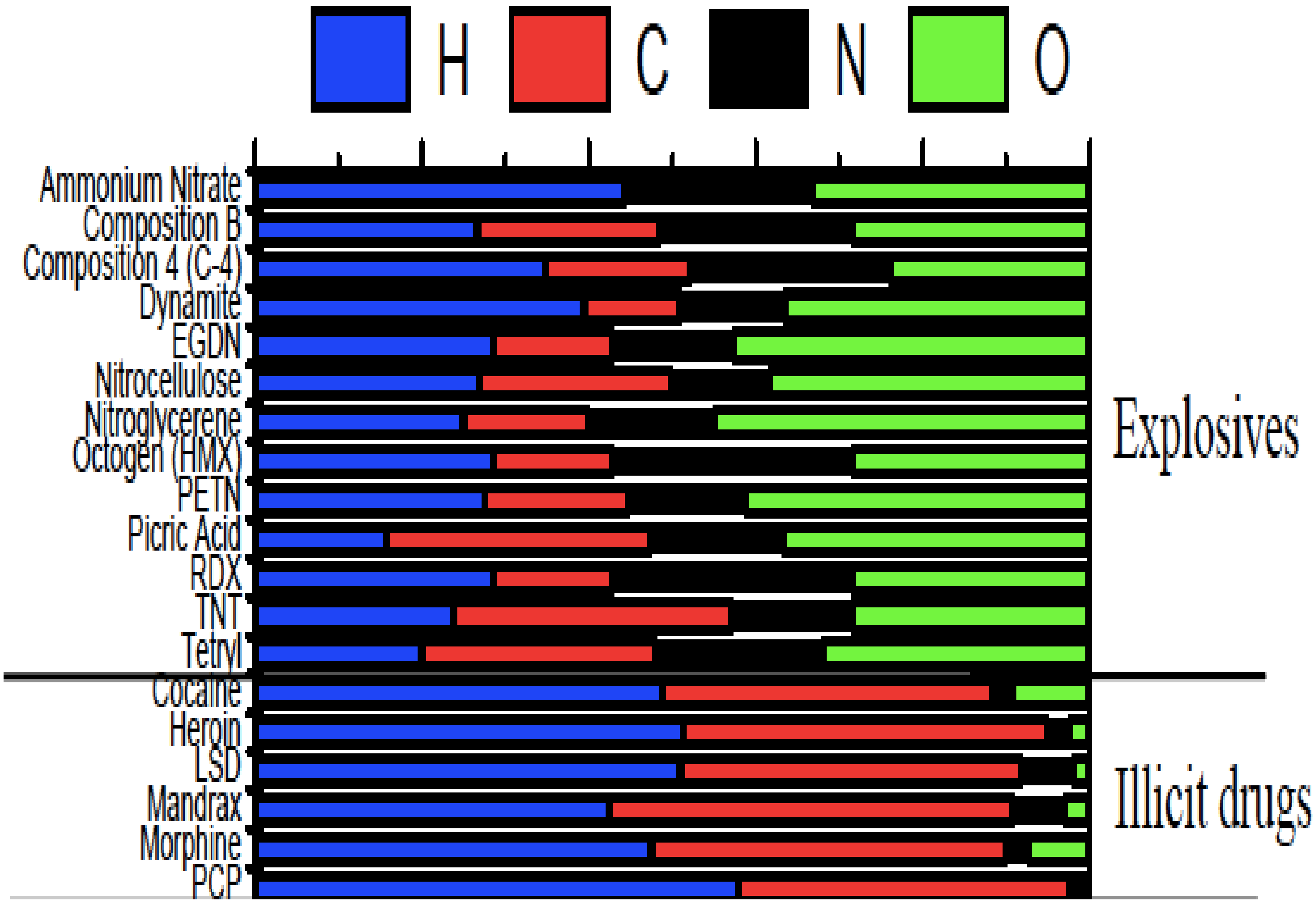
Electron Accelerator

Courtesy: Dr. A.Sinha

Detection of Explosives and Illicit Drugs



Buffler ISRP2003


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

H C N O

Explosives, Illicit Drugs

- Different Compositions of the above elements

EXPLOSIVES

Nitro Cellulose - C6H9N1O7

EGDN - C2H4N2O6

RDX - C3H6O6N6

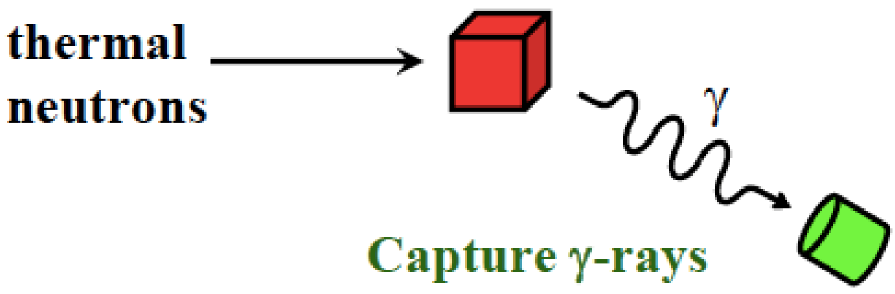
ILLICIT DRUGS

COCAINE - C17H21N1O4

MORPHINE - C17H19NO3

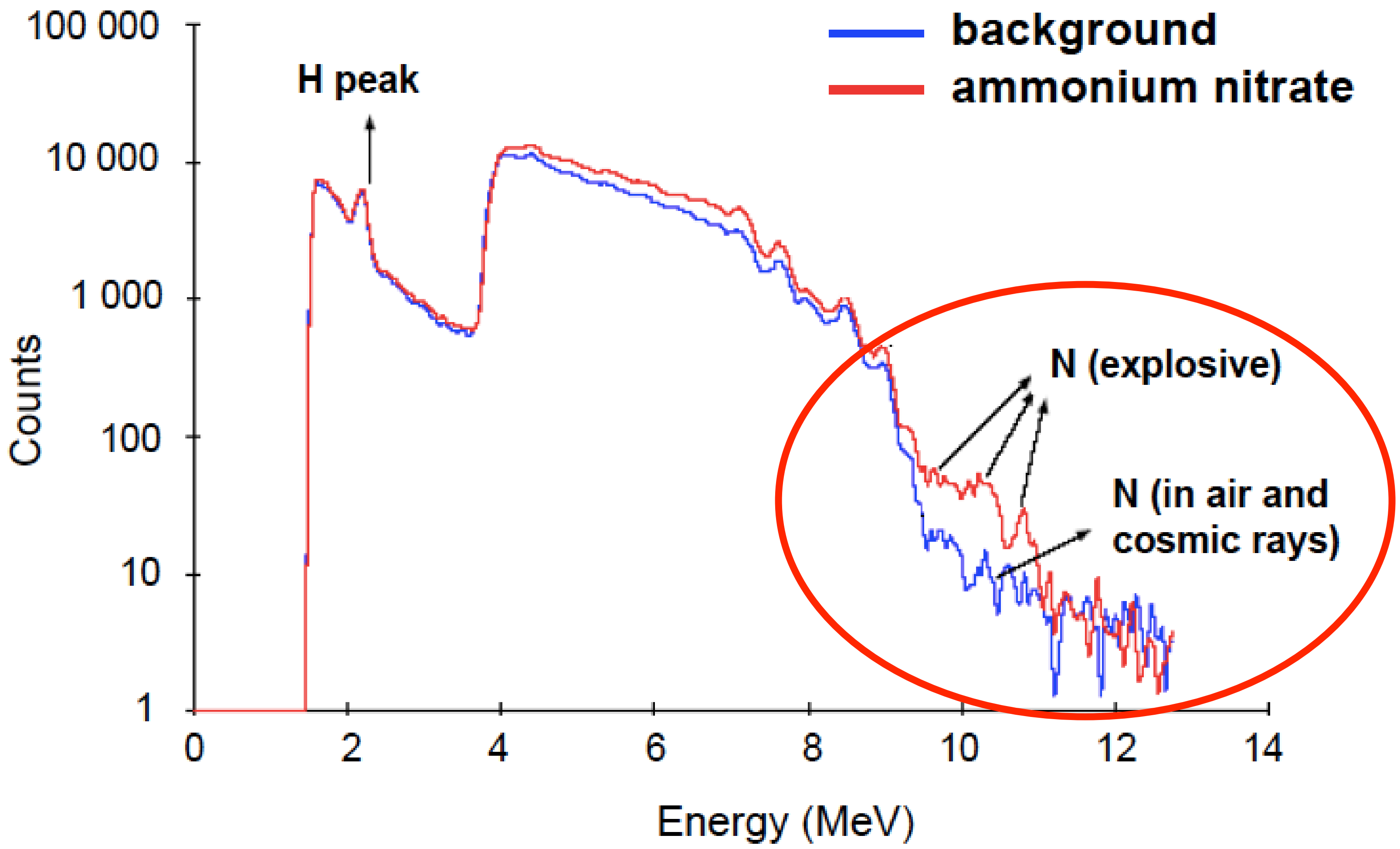
Thermal neutron capture

Neutron Energy 0.025 eV



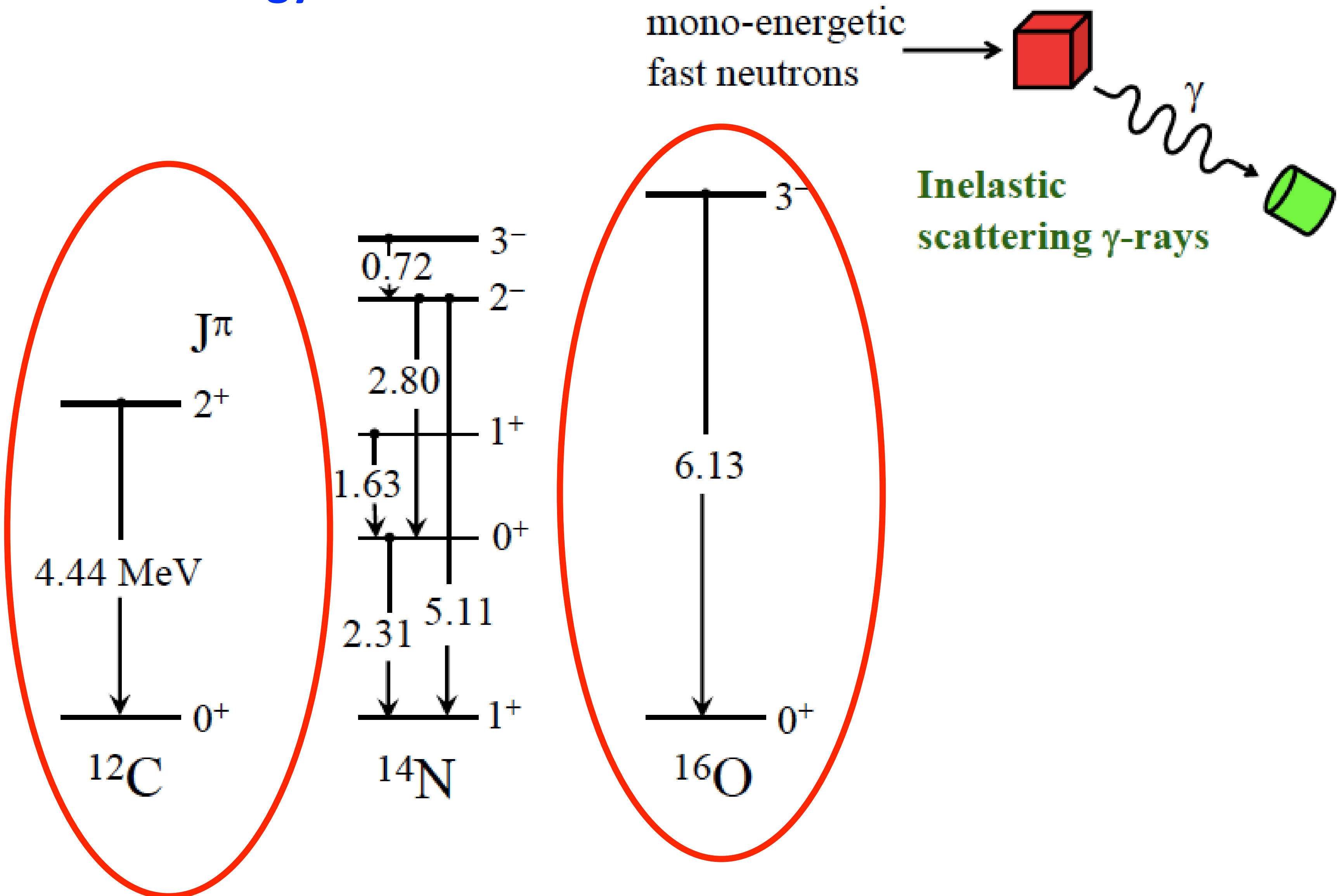
$$^{14}N + \text{thermal neutron} \rightarrow {}^{15}N + \gamma\ (10.83\ \text{MeV})$$
$$^{1}H + \text{thermal neutron} \rightarrow {}^{2}H + \gamma\ (2.223\ \text{MeV})$$

TNA spectrum for a bag with and without a small explosive

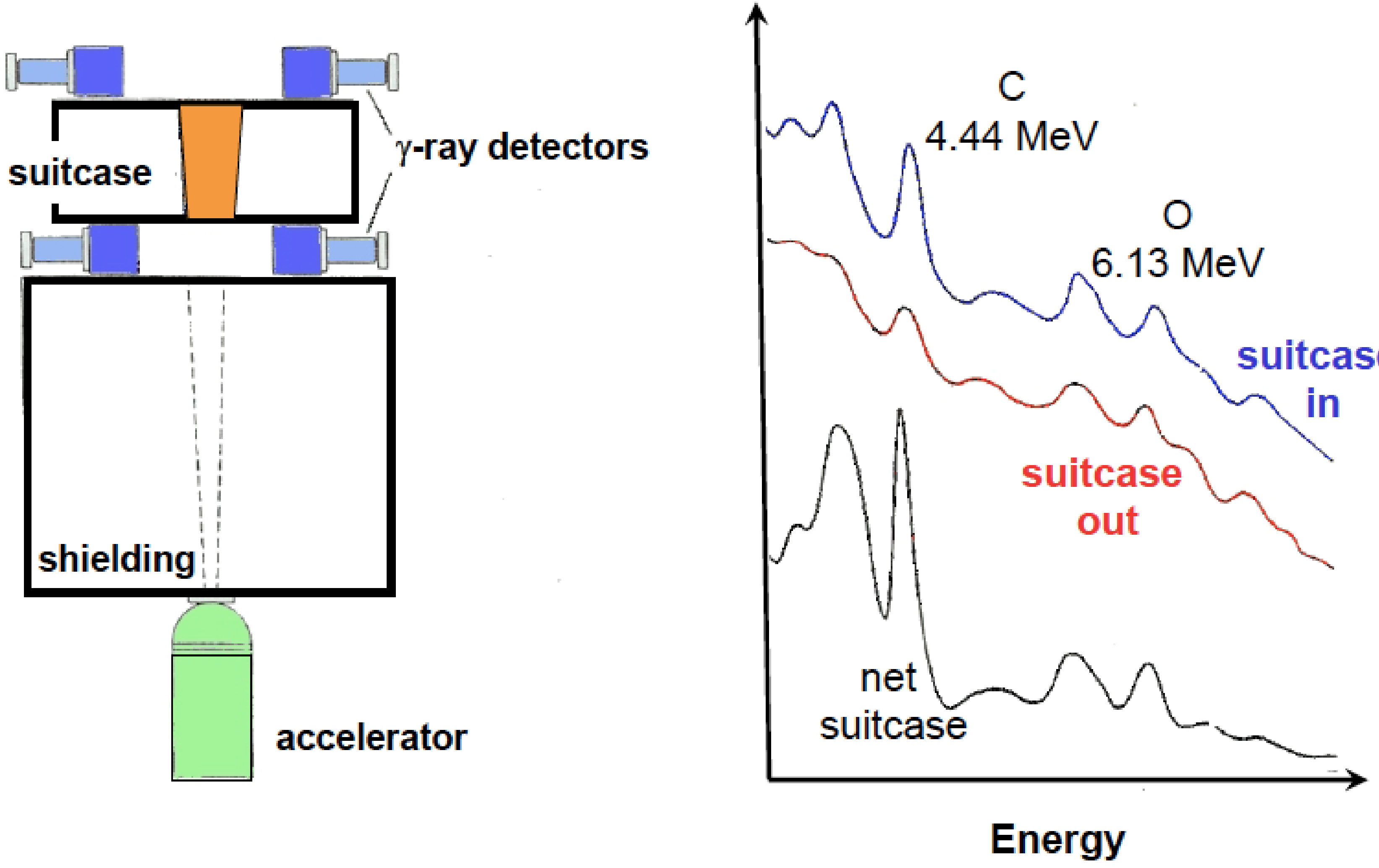


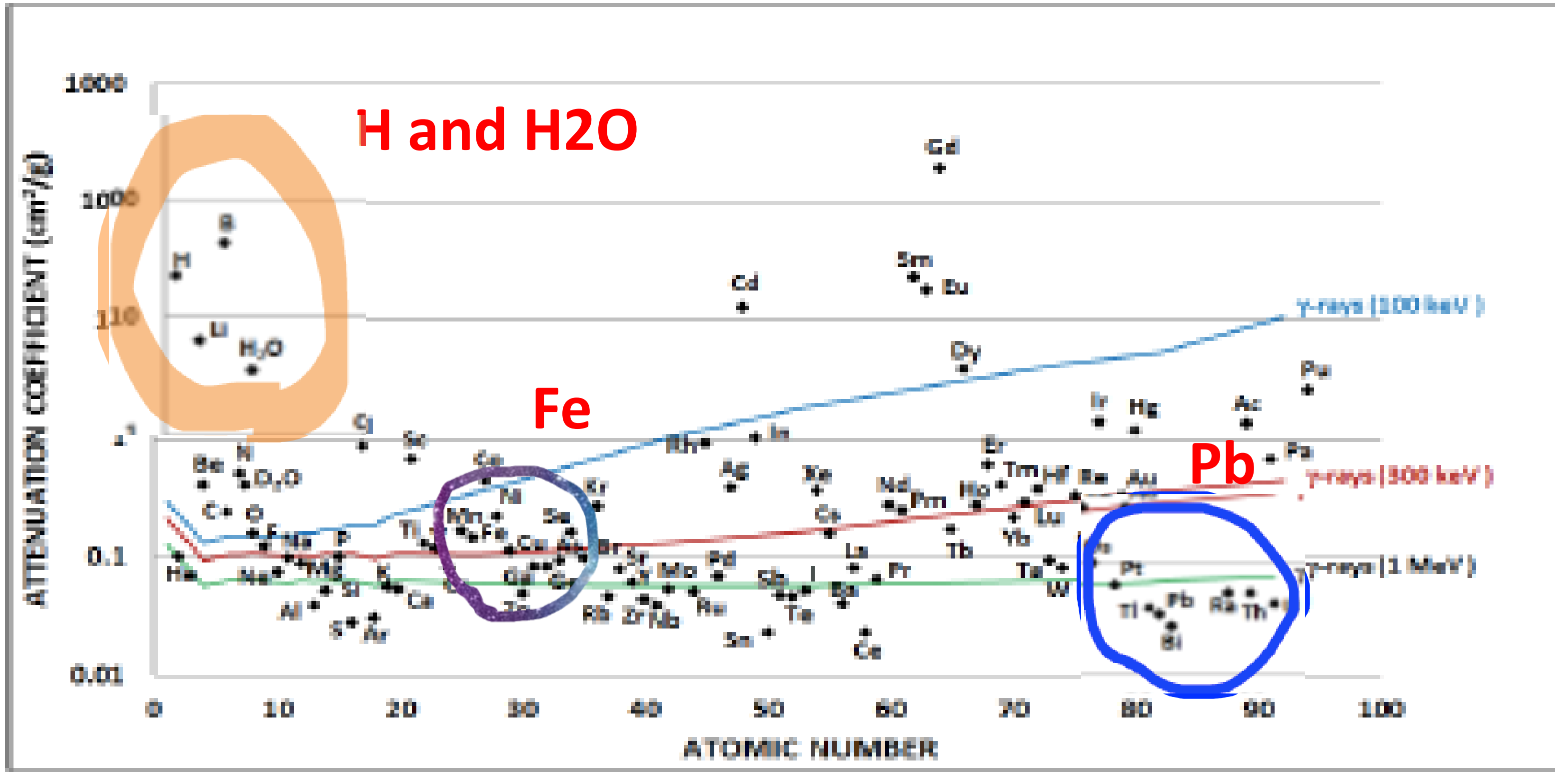
Fast neutron inelastic scattering

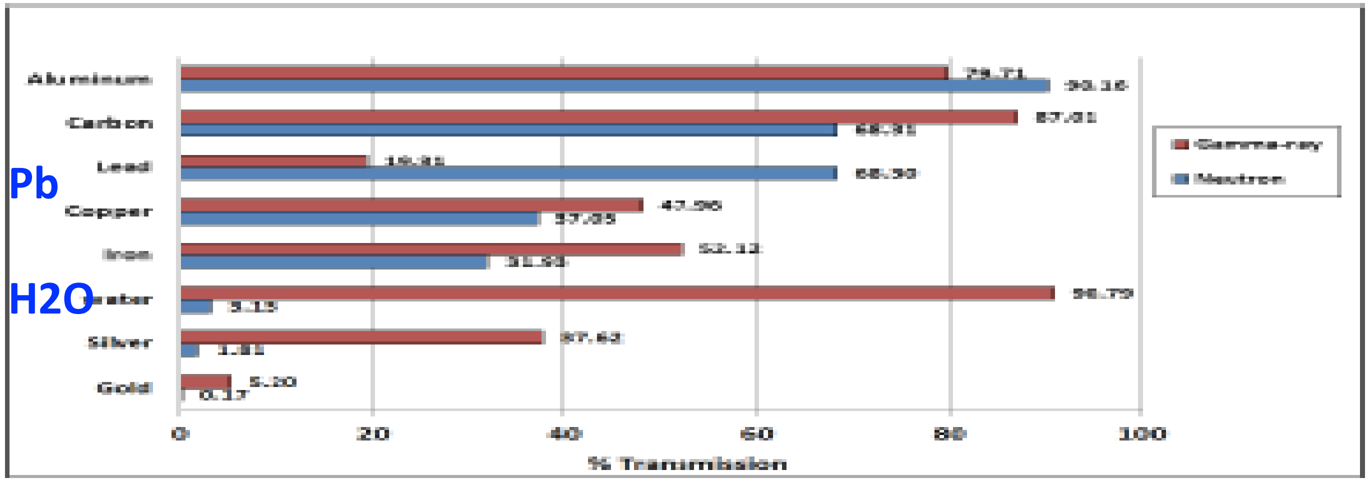
Neutron Energy ~ 14 MeV



Fast Neutron Inelastic Scattering to detect explosives in luggage







Mass Attenuation coefficient Of Thermal Neutrons

$$MAC = \Sigma / \rho$$

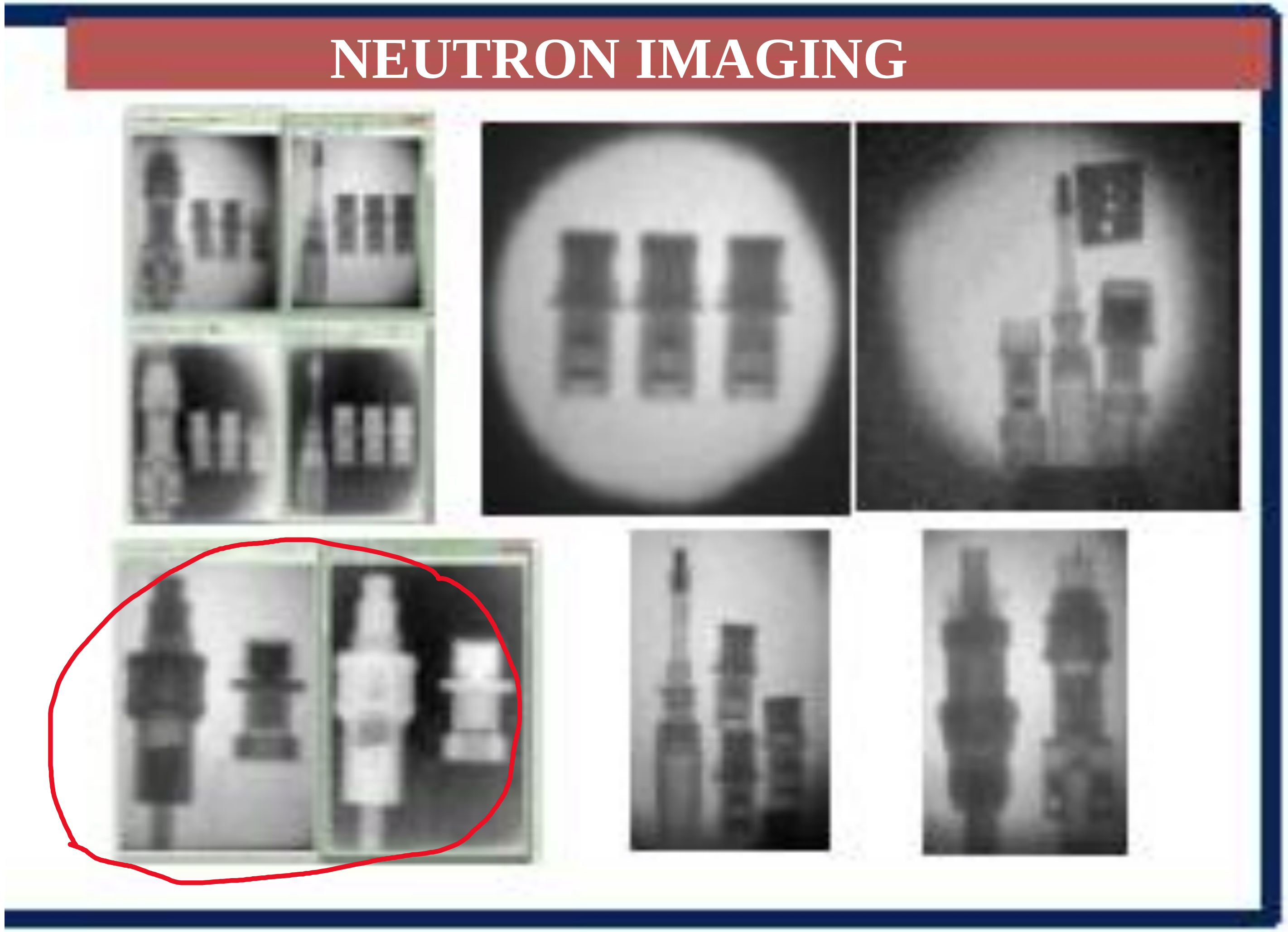
$$\Sigma = 6.0 X 10^{23} \sigma \rho / A$$

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

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

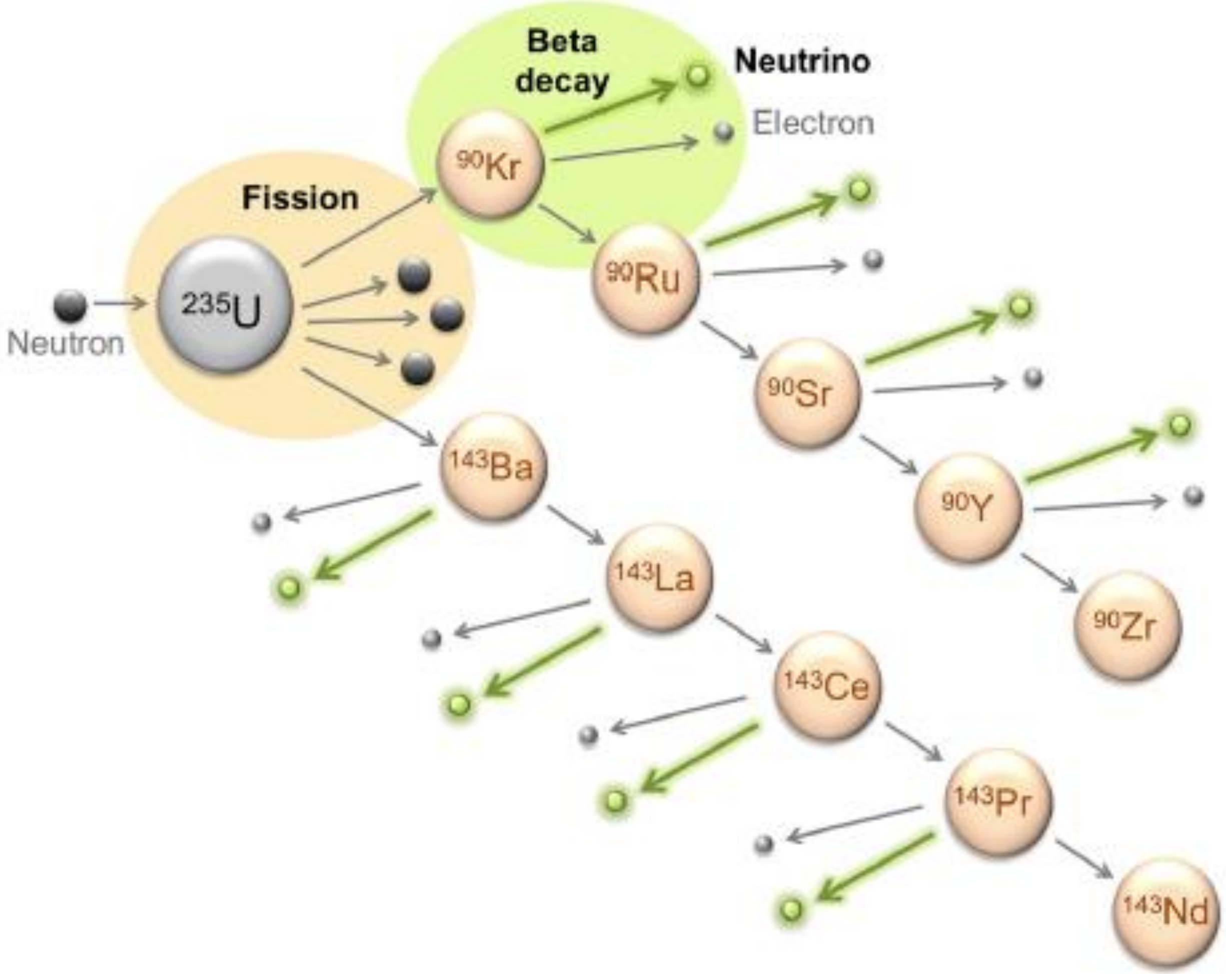


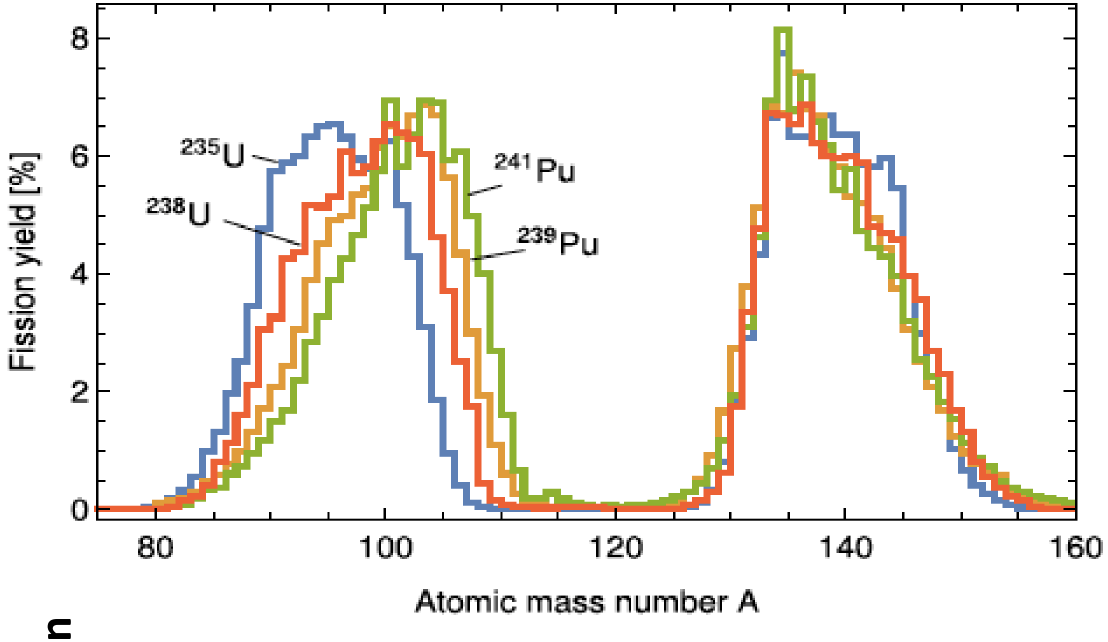
Pyrotechnic devices – mg quantity explosive inside SS vessel. Crucial for space programme. How to know the right amount of explosive is present inside SS? Use thermal neutrons significantly more Sensitive to Hydrogen(in explosives) than to the SS vessel.

Courtesy: Dr.A.Sinha

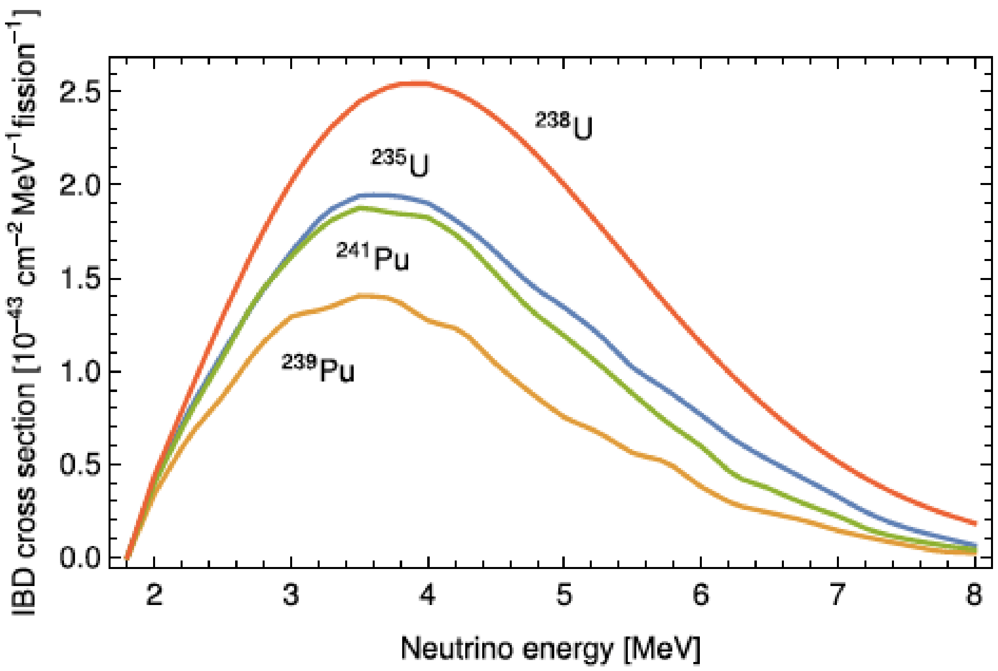
Neutrino Detectors as Tools for Monitoring a Reactor

RMP 92 (2020) Bernstein et. al.





Detection cross section per fission



Cerium Ruthenium Low-Energy Antineutrino Measurements for Safeguarding Military Naval Reactors (submarine). PRL 128 (2022) 240803

Fission fragments beta decay and emit antineutrinos even when reactor is shut

		^{144}Ce	^{106}Ru
CFY.	235U fission	0.055	0.004
CFY.	239Pu fission	0.037	0.042

Measurement of ratio of Ce to Ru is a measure of Pu fission fraction

To Sum Up:

Basic research - Intrinsic interest

- Connection to other disciplines

Doing basic research - use this Knowledge for development of technologies relevant to society

Today’s Science is Tomorrow’s Technology!

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

References

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- *www.accelerators-for-society.org*

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