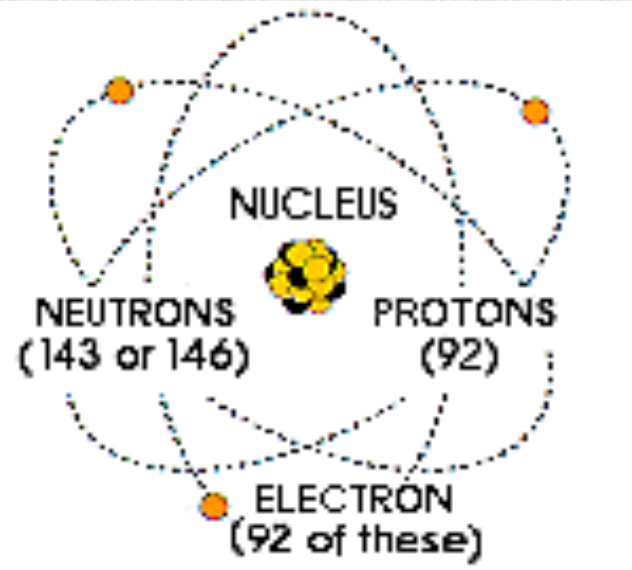


Nuclear Technologies for Society

Amit Roy

Institute Public Lecture at Indian Institute of Technology, Indore,
6 November 2024

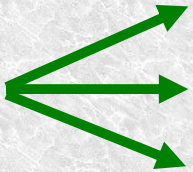
Nuclear Technologies

1. Accelerators – Electrons and Ions of high energies.
2. Reactors - Energy Source.

   Both can produce radioisotopes.

3. Detectors - Photons, Charged particles, Neutrals

Societal Applications



use of radio isotopes
source of energy
use of high energy particles.

Radiation from Nuclei have

penetrating power,
ionizing power,
sensitive detection

Medicine

Radio-therapy, PET, SPECT, Hadron-therapy

Protein Structure & Drug Discovery

Environment & Art

Trace element Analysis, Accelerator Mass Spectrometry

Industry

Semiconductors, Ion-beam lithography,

Materials modification (Adhesion, Hardness, Corrosion resistance)

Radiation Processing

Cross linking of Polymers, Curing of Paints & Varnishes,
Detoxification of Wastes, Purification of industrial gases

Sterilisation of medical supplies

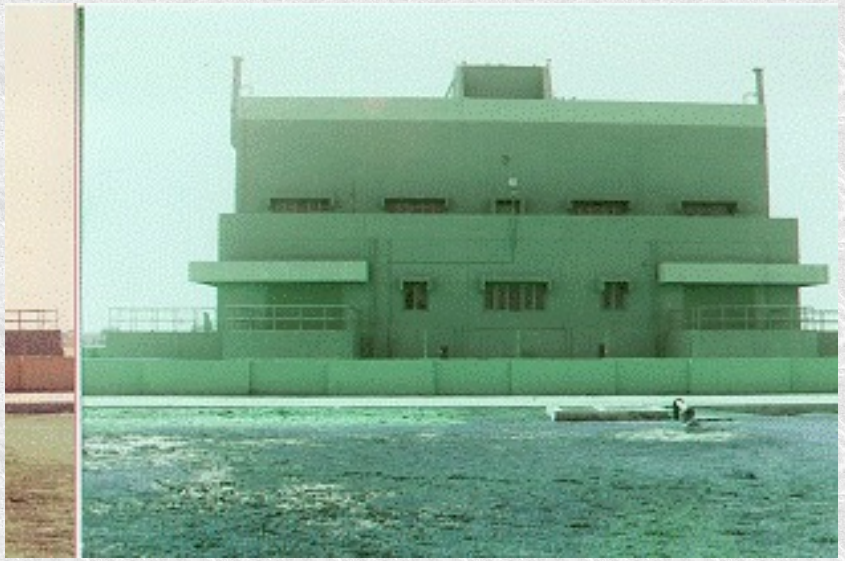
Security: **Using neutrons, Gamma rays, Muons**

Agriculture: **Sterilization of food, New varieties of plants**

Energy Generation

STERILISATION OF MATERIALS

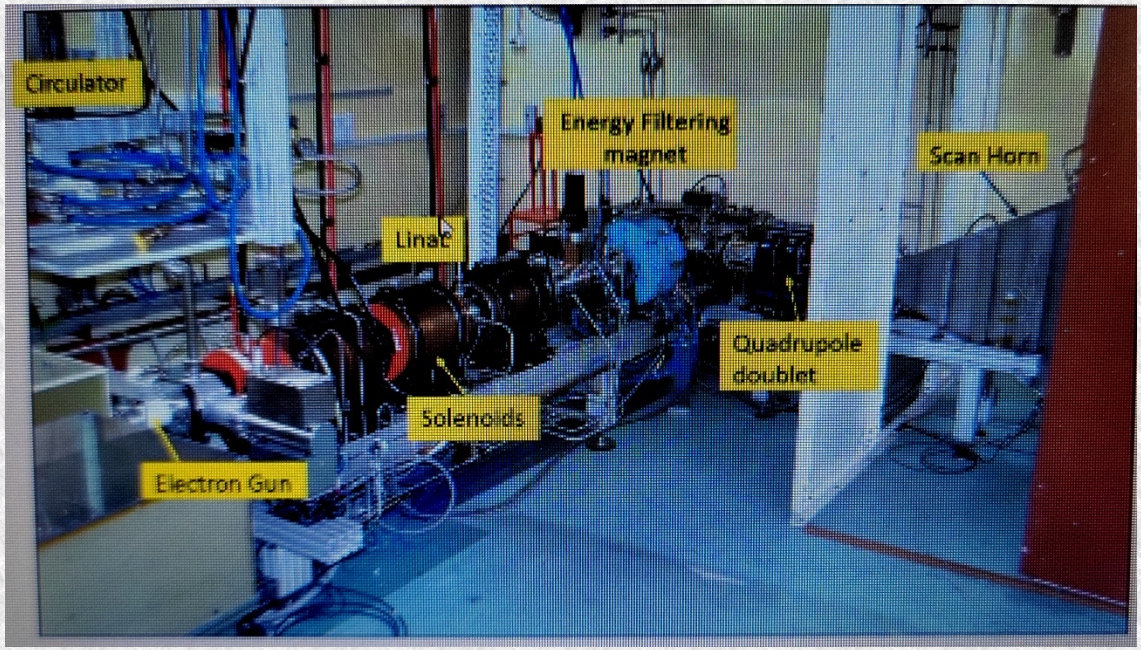
Medical products sterilization by gamma rays at Isomed plant at Trombay



Sewage Sludge hygienisation Facility at Vadodara using ^{60}Co

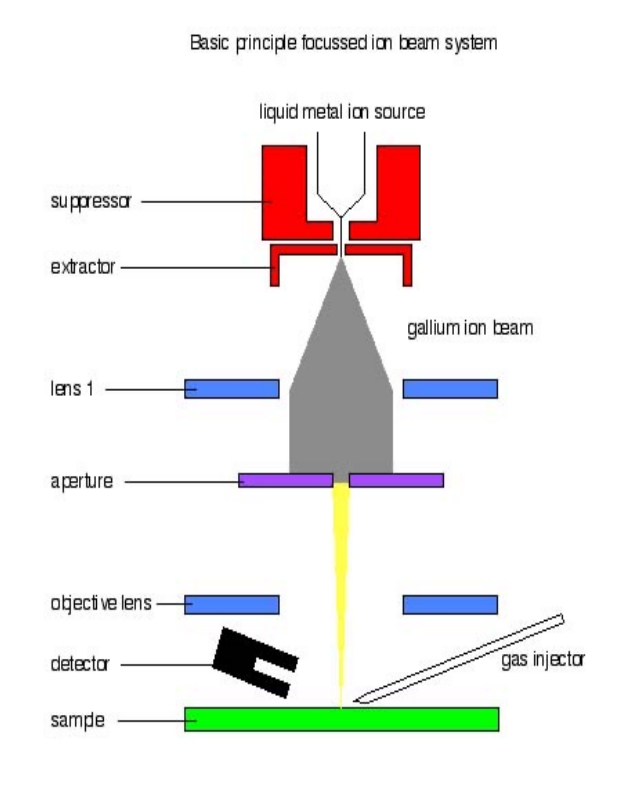
Food Irradiation:
Defence Lab, Jodhpur
Trombay, Navi Mumbai,
Lasalgaon, Indore

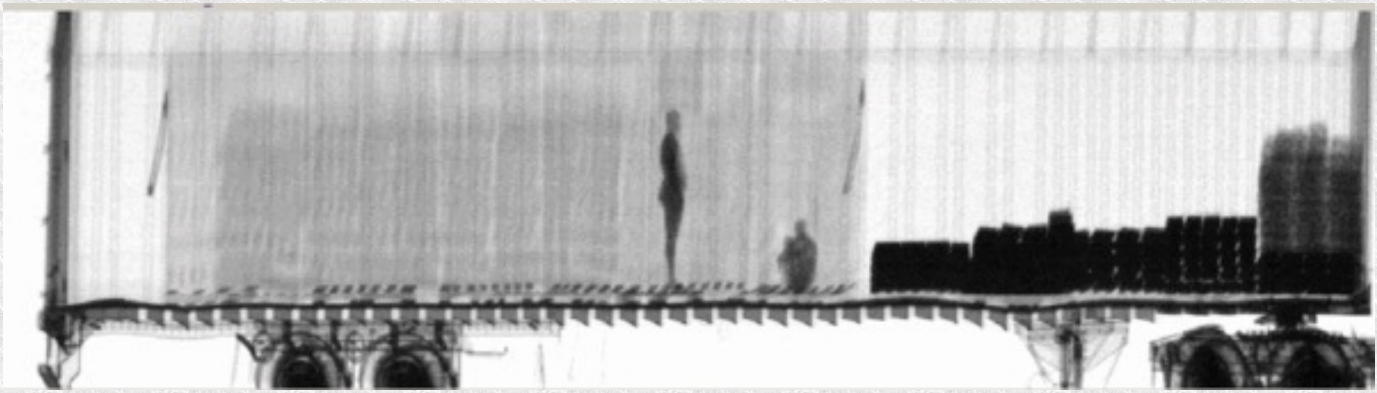
500 keV Industrial Accelerator by BARC at Navi Mumbai



10 MV, 15 kW Industrial Electron Linac, RRCAT

Industry & Security

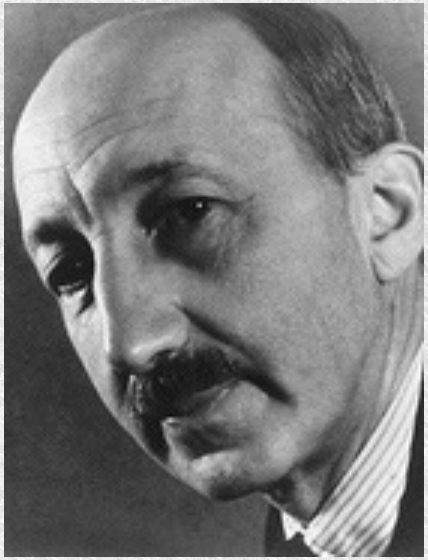




Cargo scanning image of a shipping container showing two stowaways hidden inside.

Ion Beam Milling,
MEMs Devices,
Lithography,
Ion Implantation.

Radioisotopes as tracers, 1911.



George de Hevesy
Nobel prize in 1943
Atoms for Peace award in 1959.

He applied this technique to trace lead absorbed by plants in 1923.

(a) **Subsurface dykes; (*b*), New spring that appeared subsequently.**

Isotope techniques to identify recharge areas of springs for rainwater harvesting in the mountainous region of Gaucher area, Chamoli District, Uttarakhand.

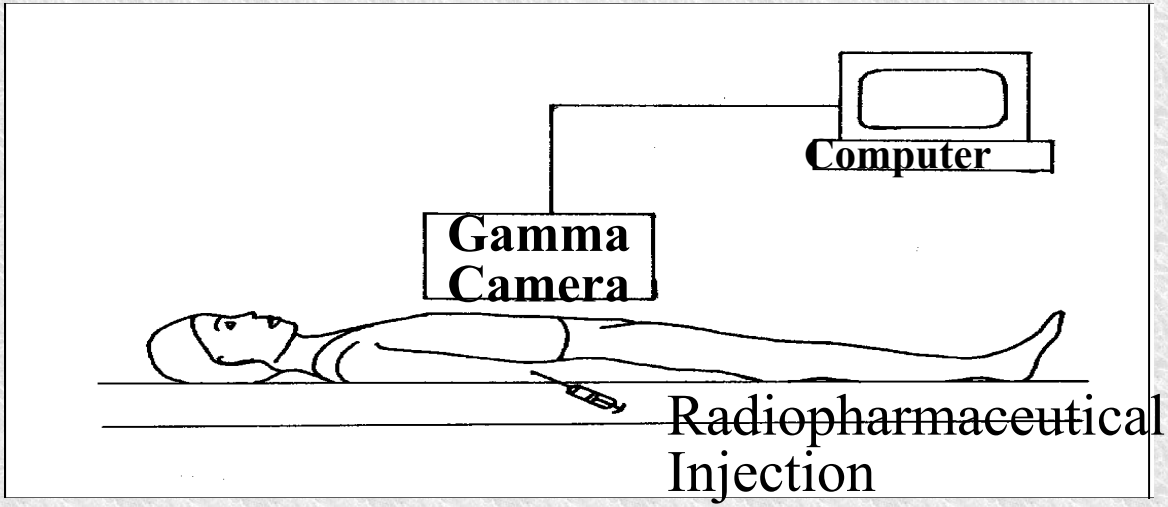
Silt movement is being studied in Hoogly river.

Management of fertiliser applications with N-15 & P-32 'labelled' compounds.

Prof. James Larkin of University of Witwatersrands, South Africa injecting low-dose of non-toxic radioisotope into horn of a Rhino in Mokopane, June 25, 2024.
Photo Credit: AFP. Part of Project to save Rhinos from poaching.

Diagnostics

Single Photon Emission Computerised Tomography (SPECT)



Radioisotopes used: ^{99m}Tc , ^{201}Tl

Radio-immunoassay:

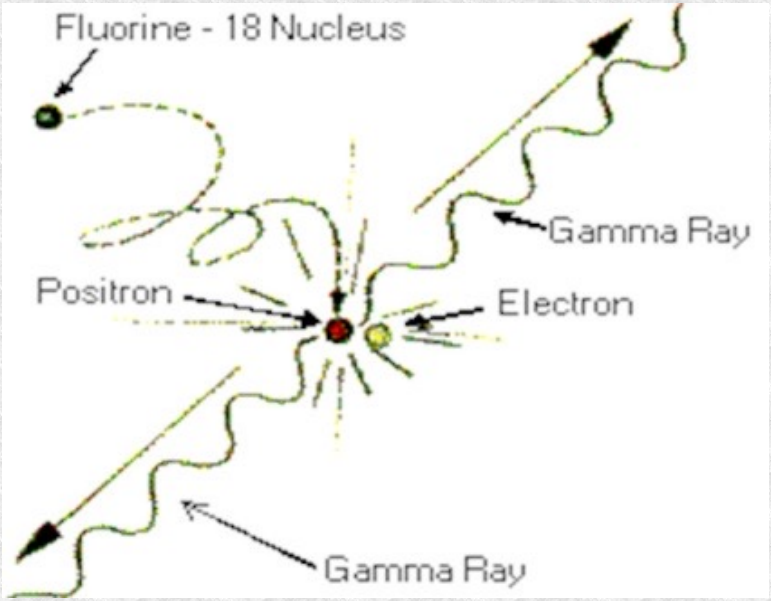
Biochemical analysis for low concentrations of hormones, enzymes, hepatitis virus, some drugs, etc.

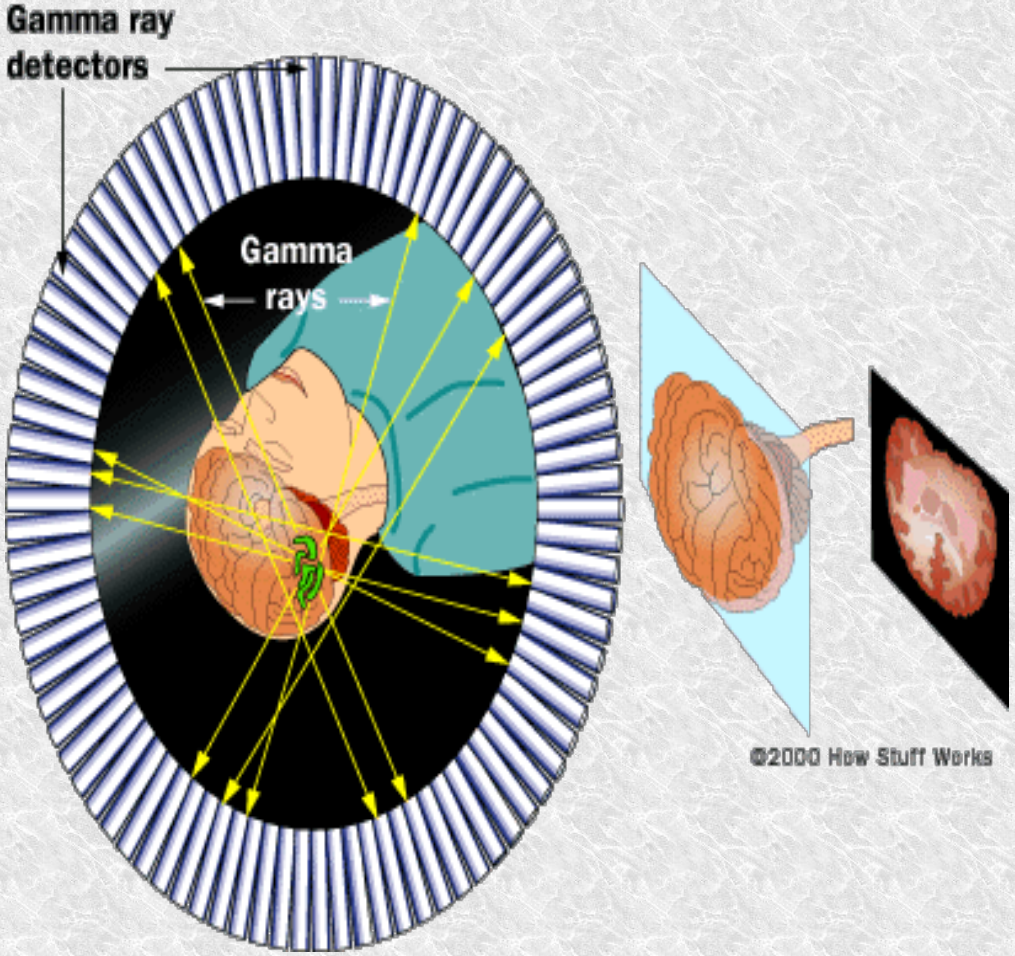
Radioisotopes used: ^{3}H, ^{14}C, ^{125}I, ^{131}I

Rosalyn Yalow
1977 Nobel

Positron Emission Tomography (PET)

reveals tumours, dynamic effects such as blood flow.



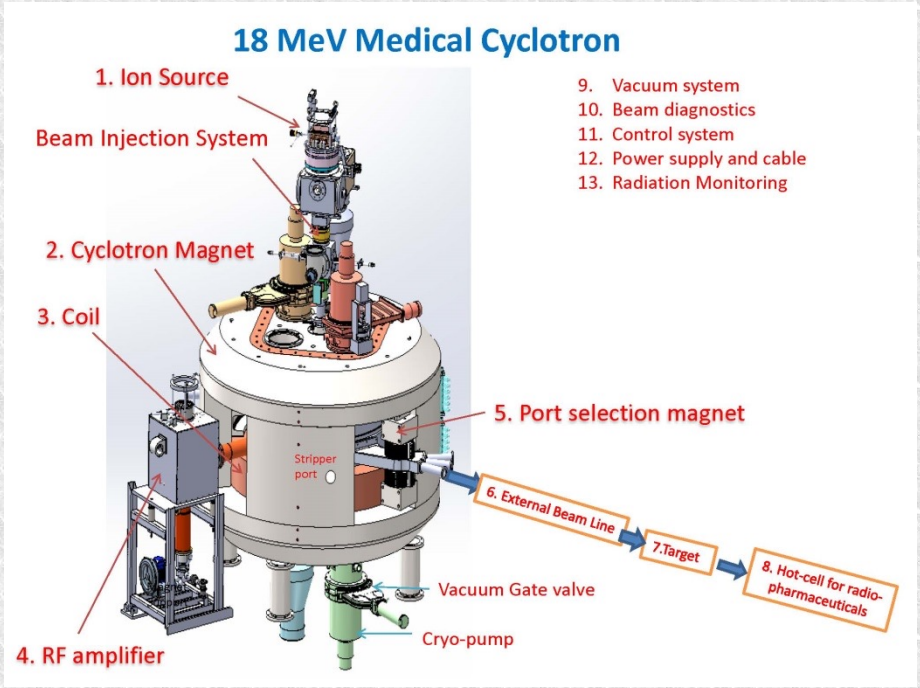


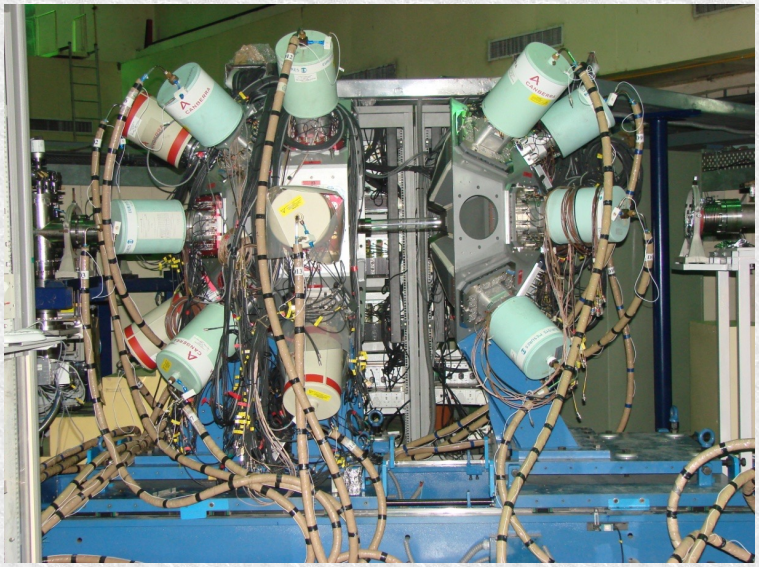
Isotopes used:

^{15}O (2 min), ^{13}N (10 min), ^{11}C (20 min), ^{18}F (100 min).

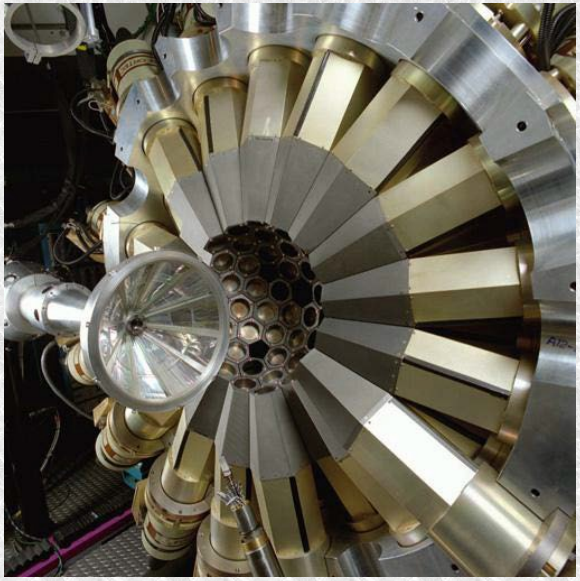
Variable Energy Cyclotron Centre

F-18, Ga-67, Tl-201, etc.

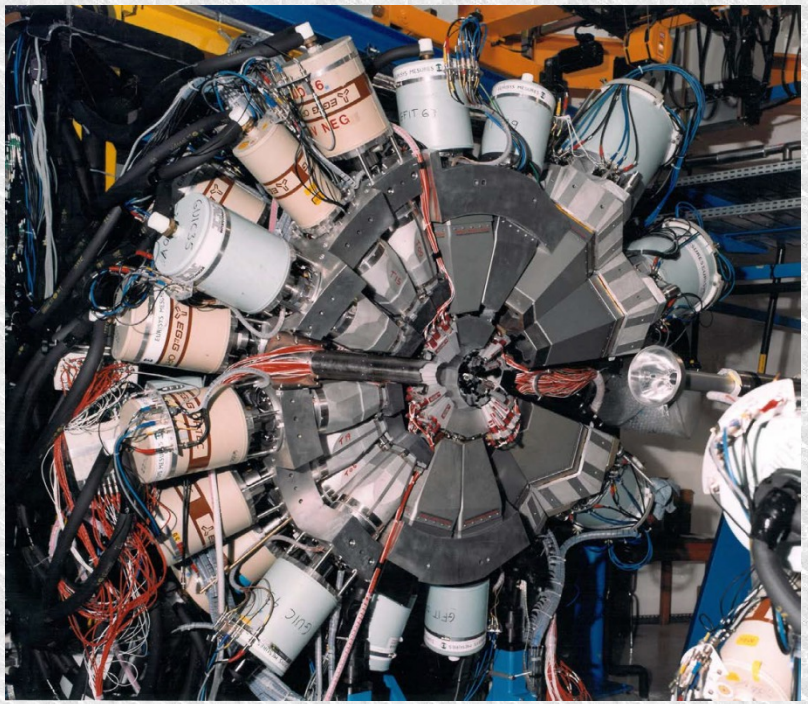




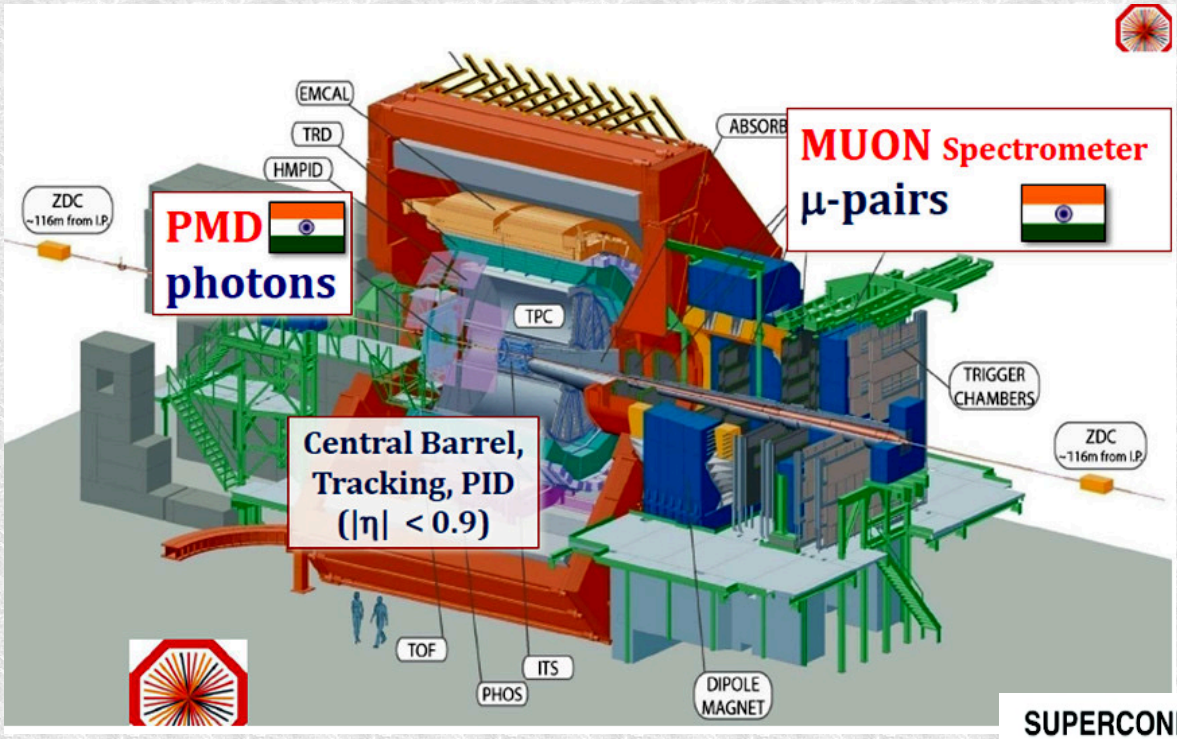
INGA@IUAC



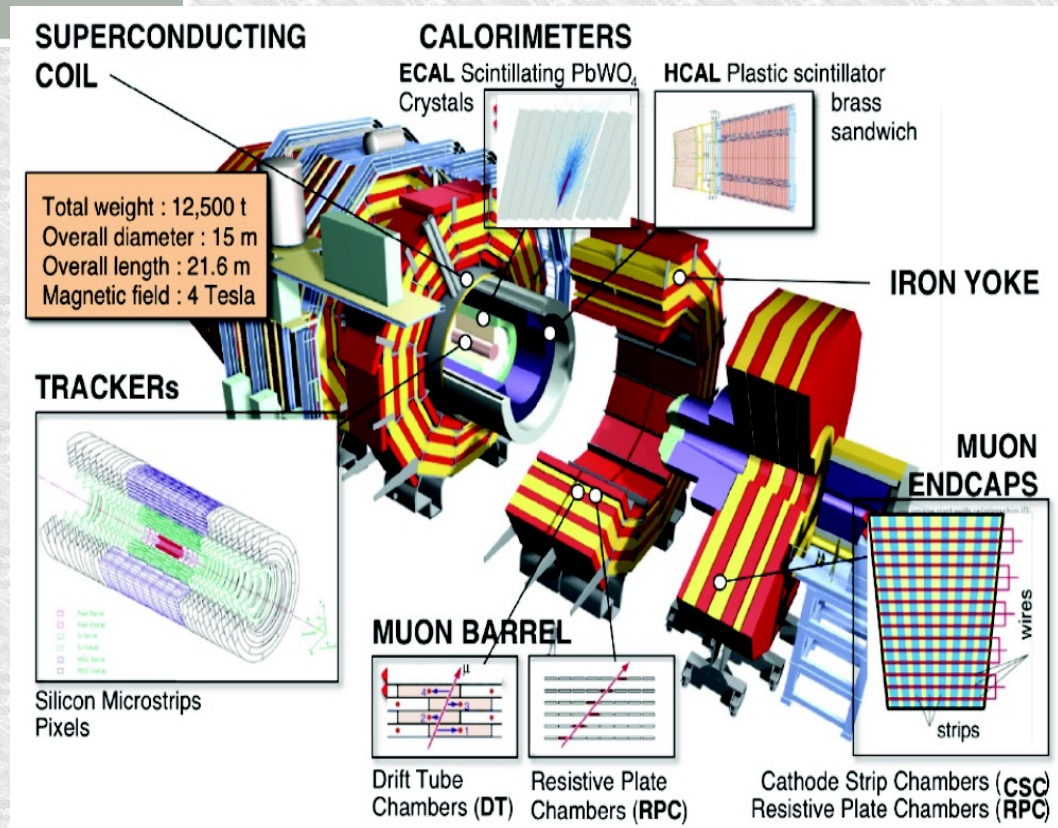
Gammasphere
110 Ge detectors (70% eff.)
escape suppression shields



EUROBALL 1997 -2003



ALICE Detector
LHC, CERN



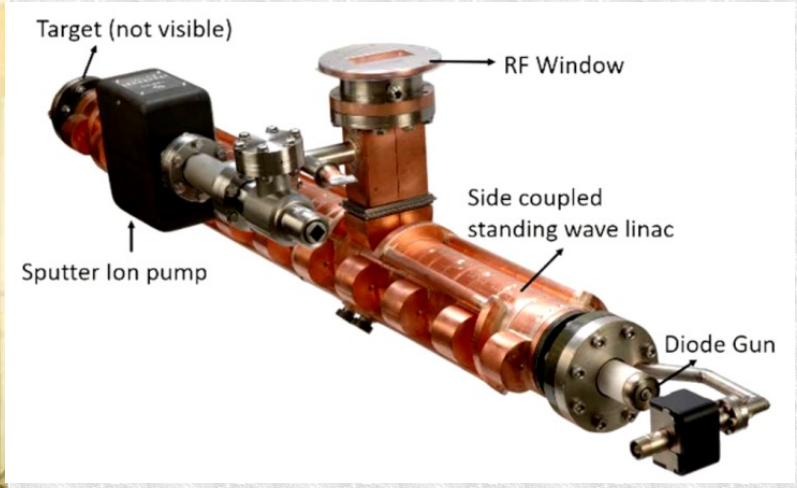
CMS detector
LHC, CERN

Therapy

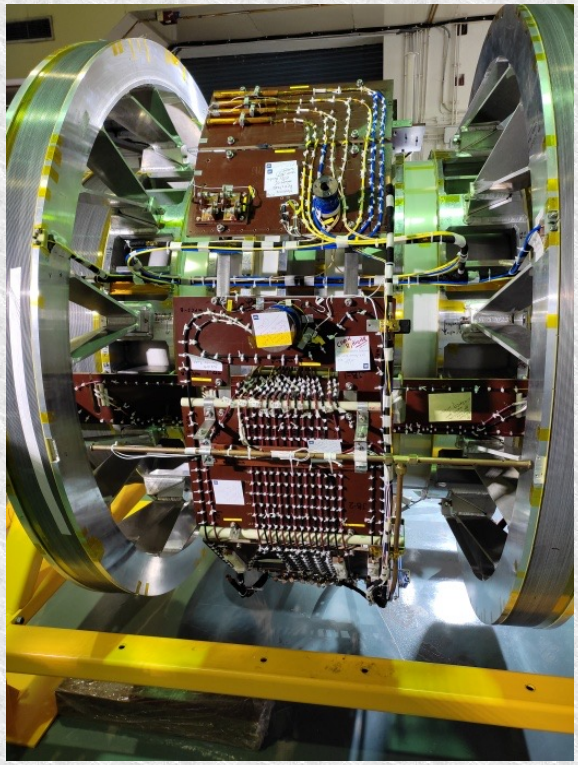
John Lawrence and Robert Stone preparing a patient for neutron irradiation at the 60” Crocker cyclotron in 1938.

Mother of E.O. Lawrence was the first cancer patient who was treated successfully with the neutrons produced using an accelerated ion beam from a cyclotron in 1939.

Jeevan Jyoti, 6 MV linac developed by SAMEER.
15 MV near completion.



30 MeV linac for radio isotope production is undergoing tests, SAMEER



Superconducting magnet for MRI, IUAC and SAMEER

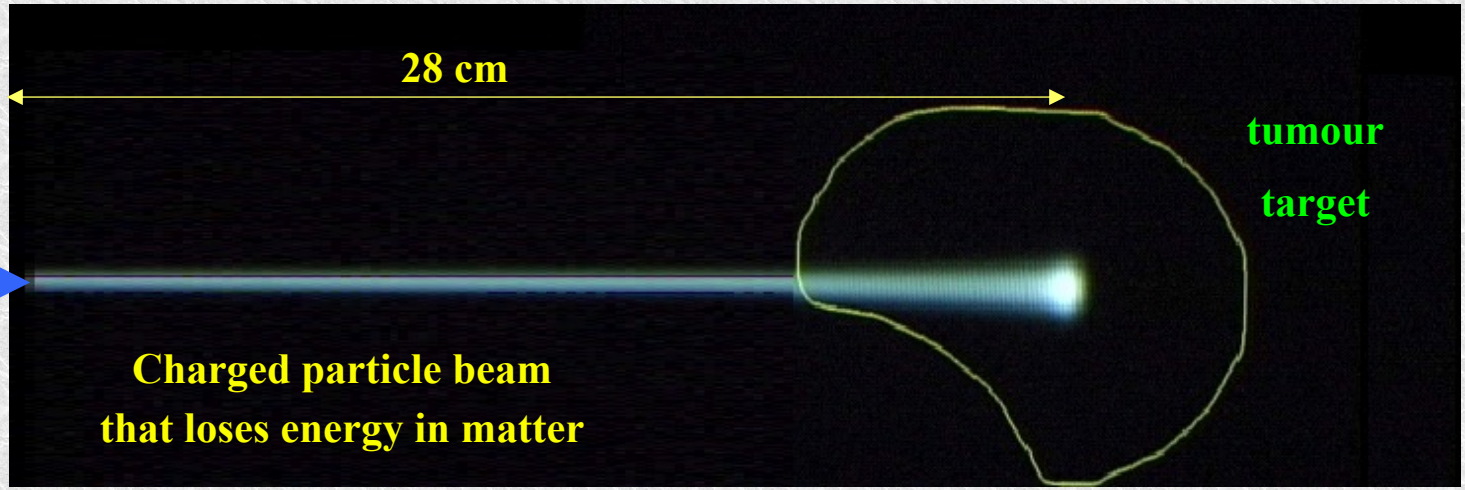
Ion Beam Therapy

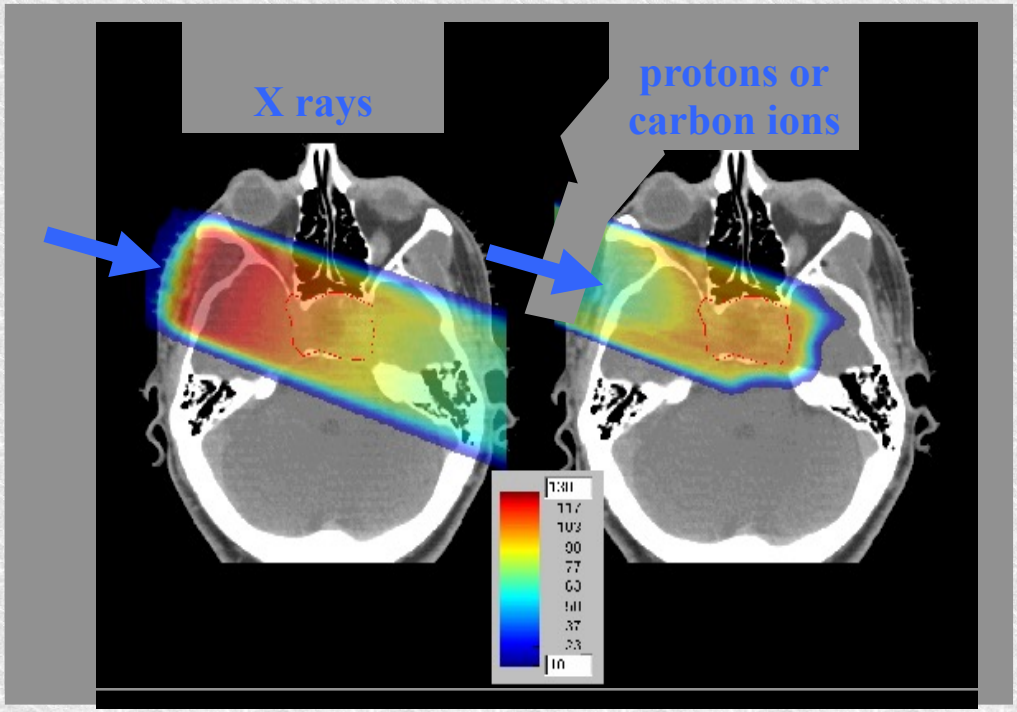
200 MeV protons

480 MeV carbon ions

which control radioresistant tumours

(G. Kraft)

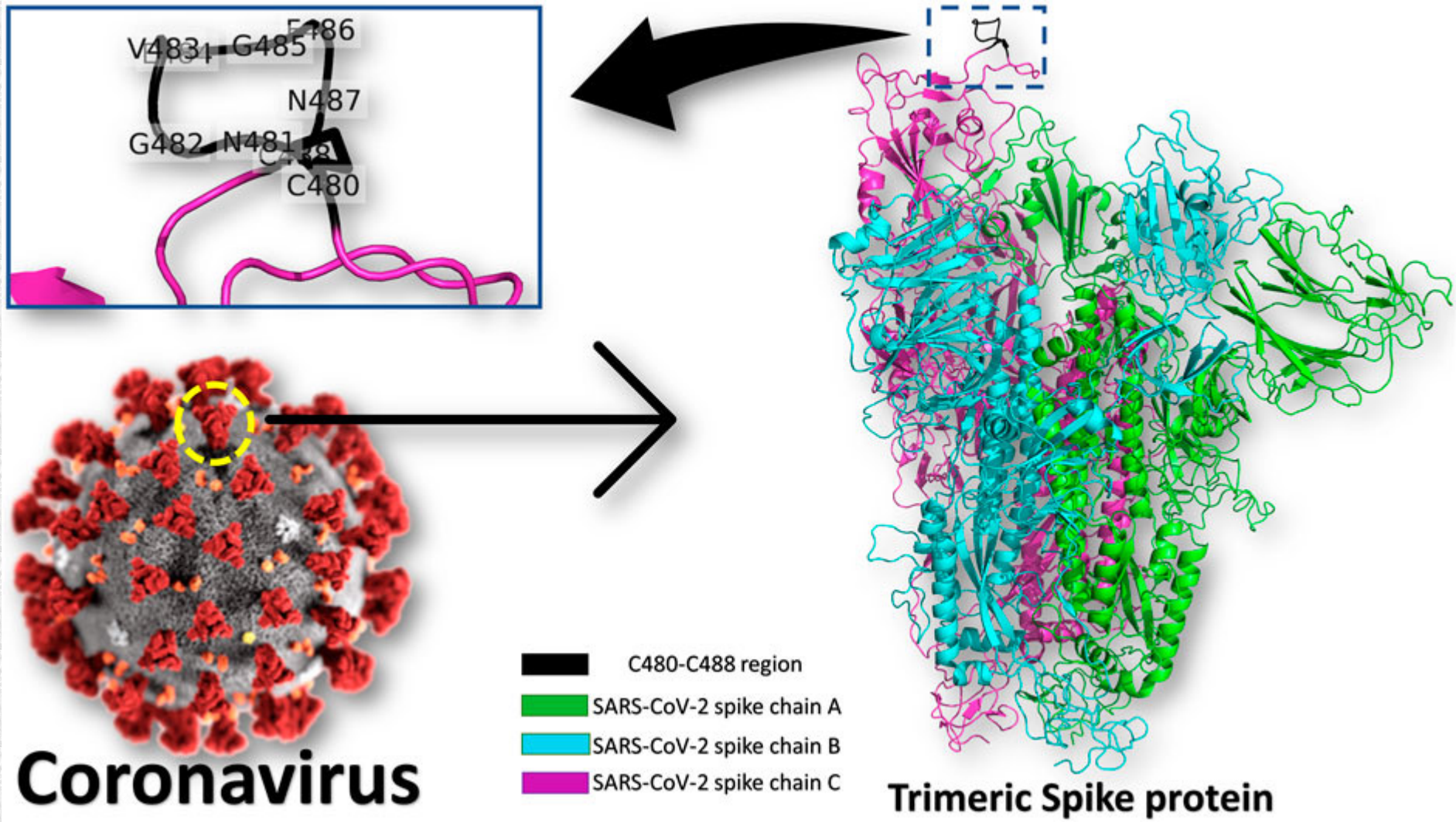




230 MeV p linac at Apollo,Chennai and TMC, Mumbai.

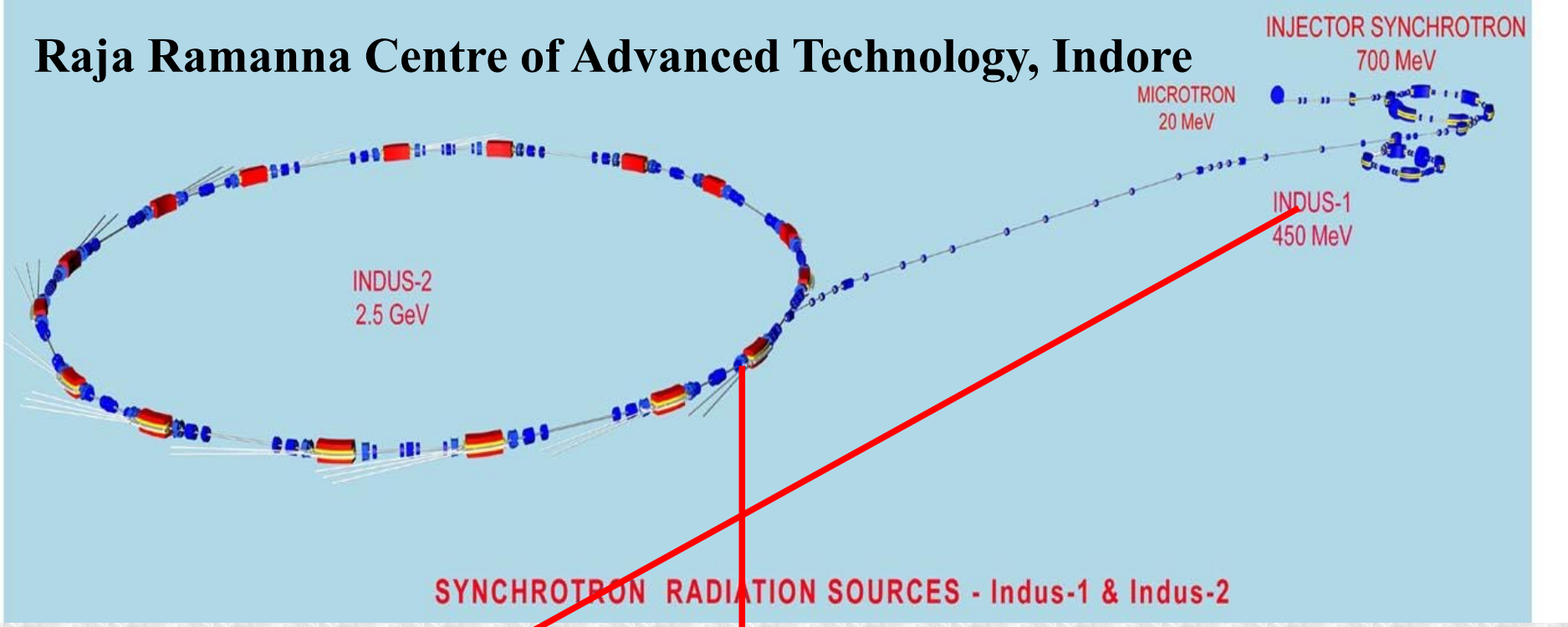
GSI

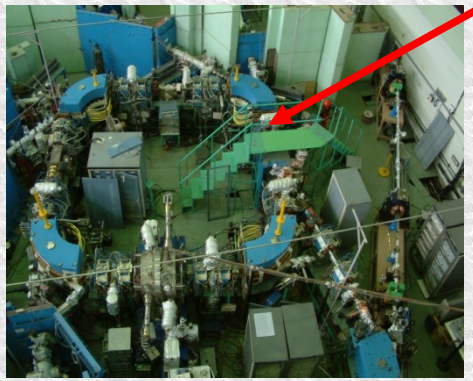
Drug Discovery

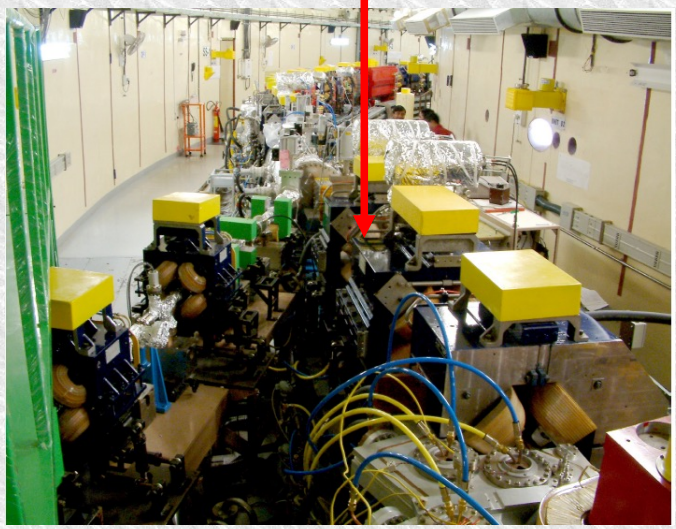


Cryo Electron Microscopy and X-ray crystallography using synchrotron x-rays.

Raja Ramanna Centre of Advanced Technology, Indore







Protein Crystallography
Structure of molecules

Radioisotopes for dating

Otzi - the Iceman

Discovered in 1991 by 2 Hikers in the Alpine ridge bet. Austria & Italy, Fairly preserved human body, ^{14}C dating was done

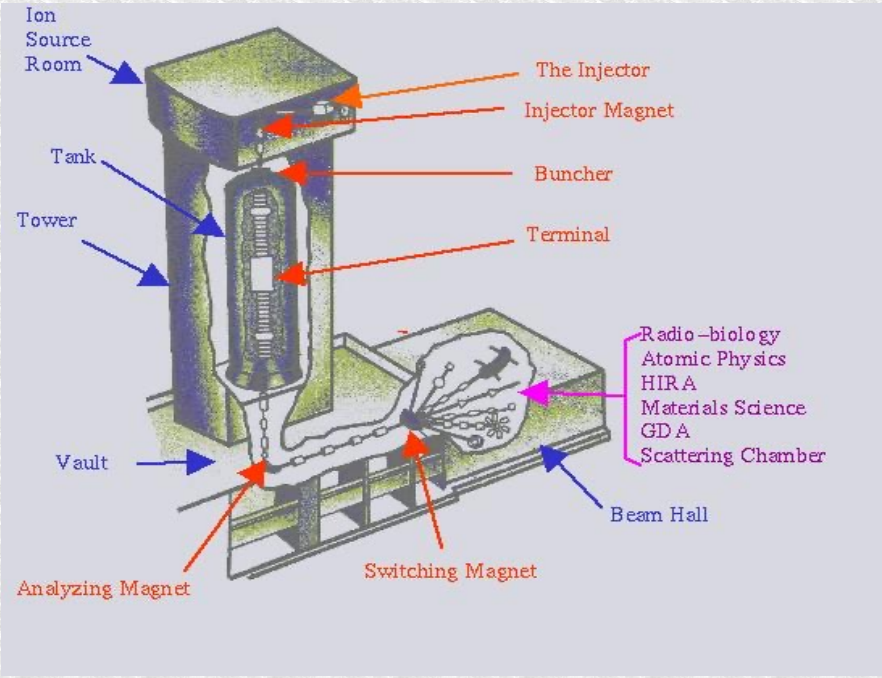
About 5300 yrs old

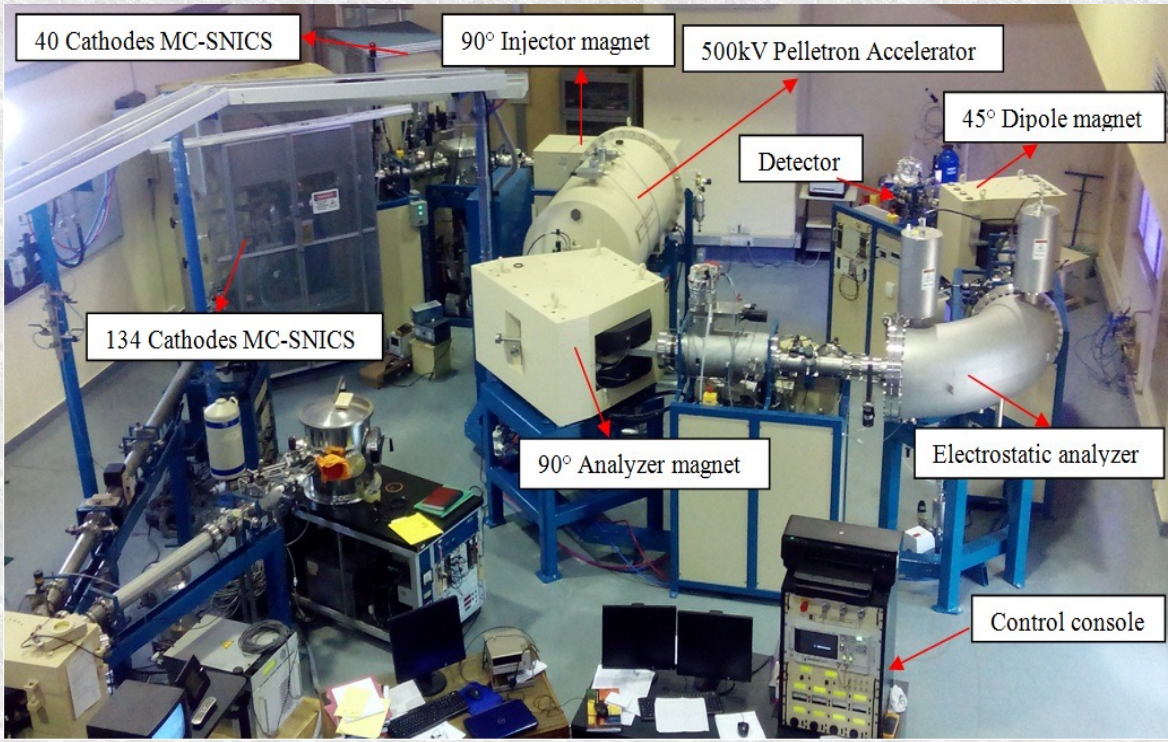
Accelerator Mass Spectrometry

Geosciences
Climate Change
Biomedicine

Oceanography
Atmospheric Sciences
Forensic Science

Inter-University Accelerator Centre





RBS, PIXE, Ion beam modification of materials, Radiation Biology, AMS

^{14}C, ^{10}Be, ^{26}Al

Detection Level ~ 10^{-11} – 10^{-15}

Perfume industries (natural vs synthetic)

Tsunami records of the last 8000 years in the Andaman Island, India from mega and large earthquakes: Insights and recurrence interval,
Javed N. Malik et al., Scientific Reports 9, Article No 18463 (2019).

Individual Energy Consumption (adopted from UNESCO Courier)

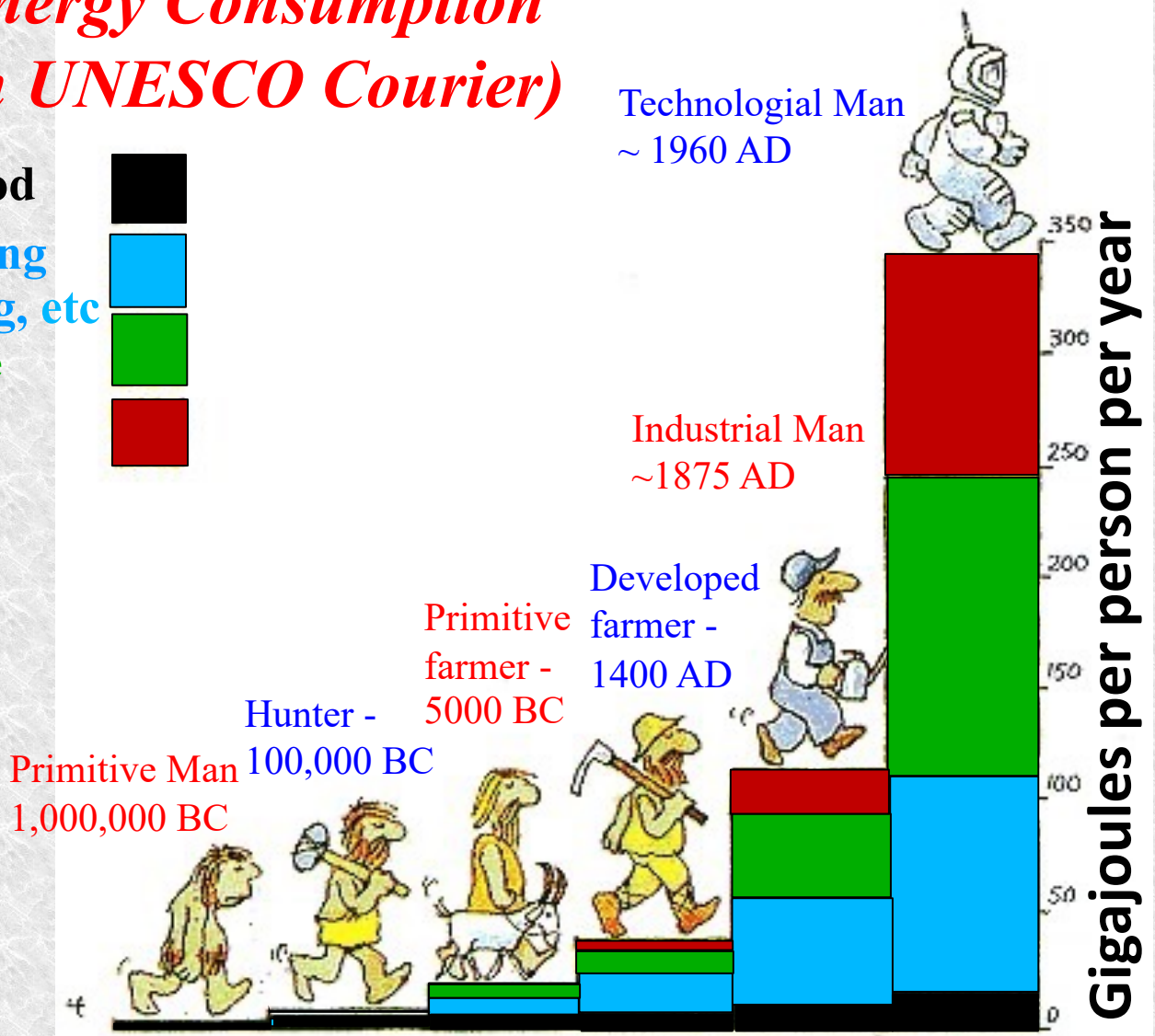
Energy Consumed in the form of Food

Domestic: Energy for Cooking, heating

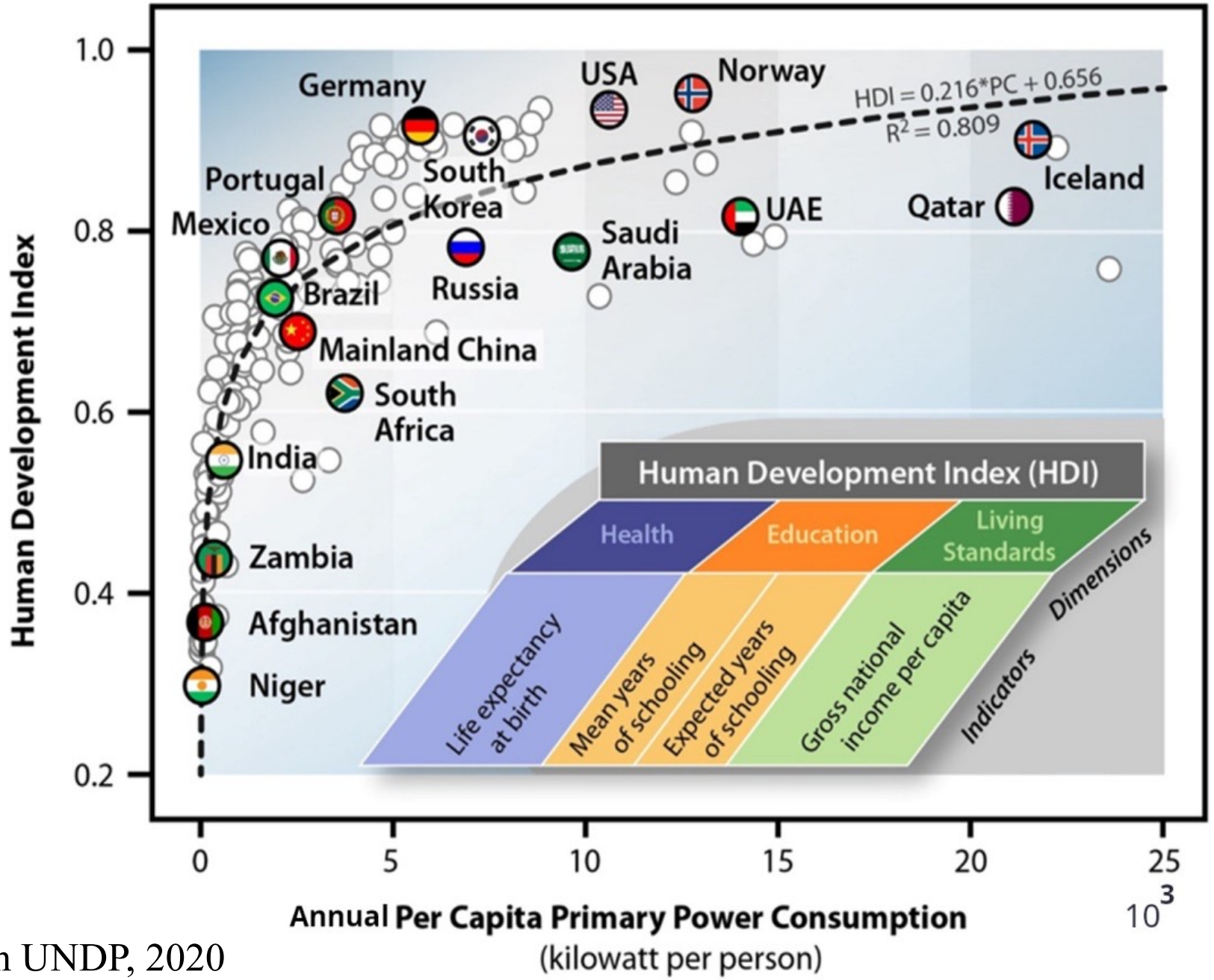
Services: Office work, trade, teaching, etc

Energy for Industry and Agriculture

Energy for Transport



32% of the world's population consumed 55% of the world's energy production in 2019



Data from UNDP, 2020
OurEnergySource.org

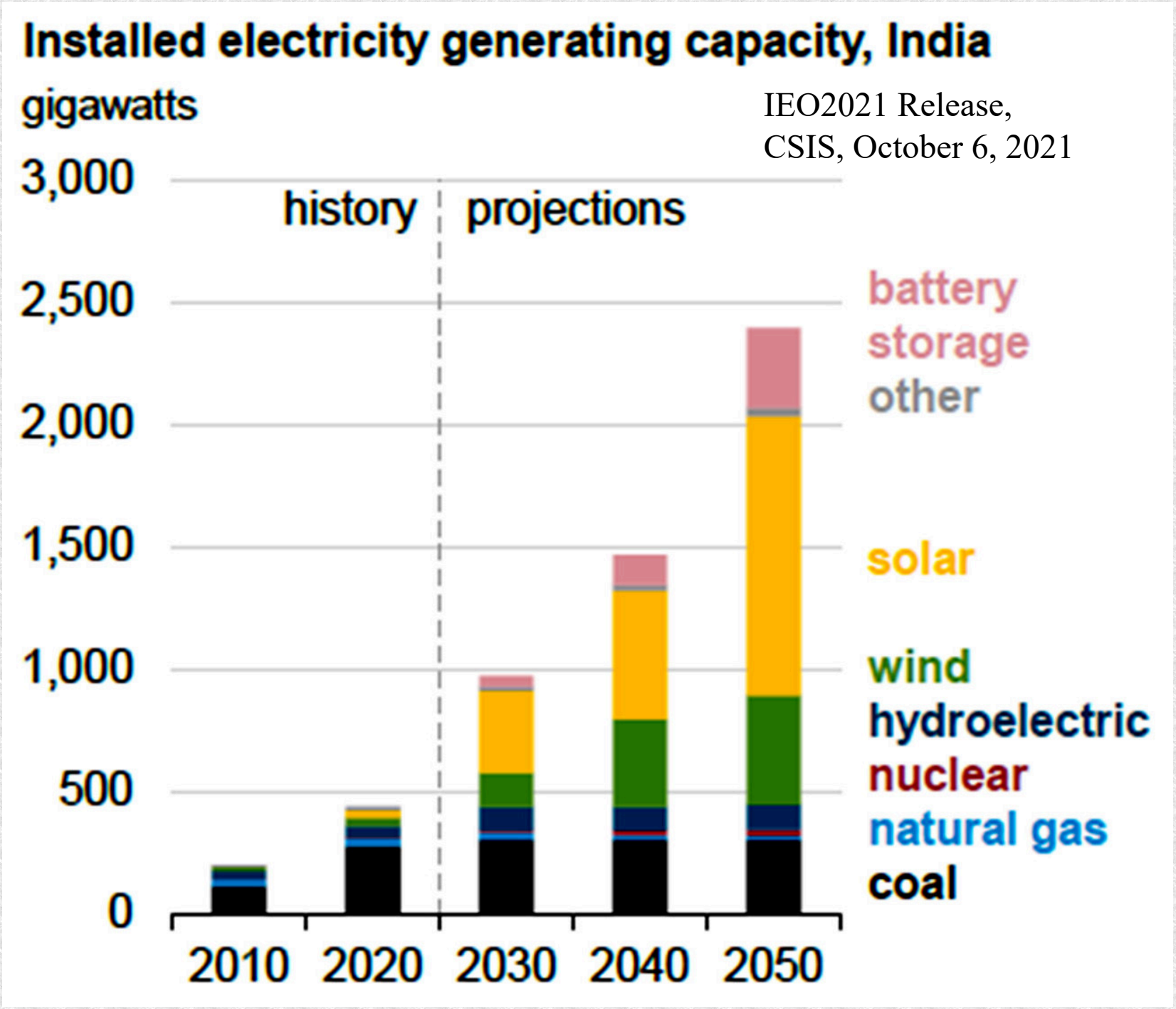
For a sustainable society we need,

Increase in energy generation and access to energy for all.

Renewable component of energy supply has to increase, but it is intermittent. Storage systems are needed.

Steady power sources needed for many uses, these have to be at present, fossil fuels and nuclear.

R & D in all these areas required.



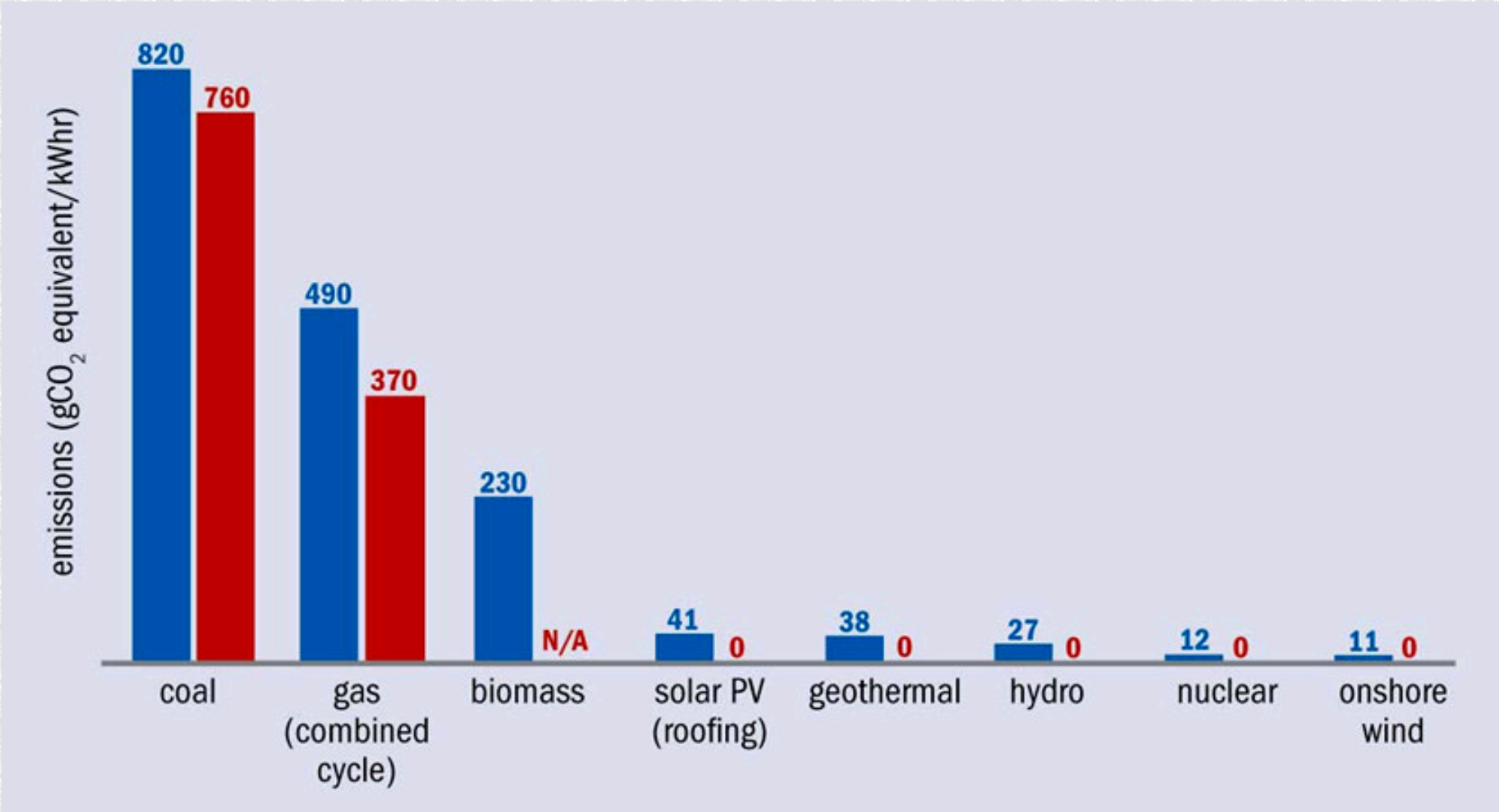
Min of Power, GoI
May, 2023

2023

16.1%

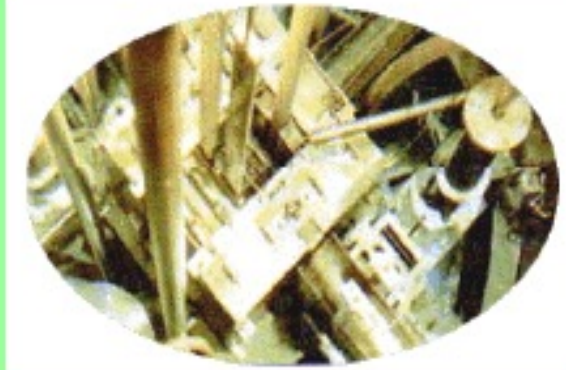
10.2%
12.4%
1.6%
6.0%
50.9%

Case for Nuclear Energy



Climate Change 2014: Mitigation of Climate Change.
Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

The 3-Stage Power Programme



2 GWe, 30 Yr

Natural Uranium

PHWR

ELECTRICITY

Depleted U

Pu

Th

300 GWe, 30 Yr

Pu FUELLED FAST BREEDERS

ELECTRICITY

Pu

U- 233

Th

500 GWe, 500 Yr

U - 233 FUELLED BREEDERS

ELECTRICITY

U- 233

STAGE 1

STAGE 2

STAGE 3

Apsara Reactor, BARC

Dhruva & CIRUS reactors, B.A.R.C.

Radiopharmaceuticals labelled with ^{131}I, ^{51}Cr , ^{32}P , etc.

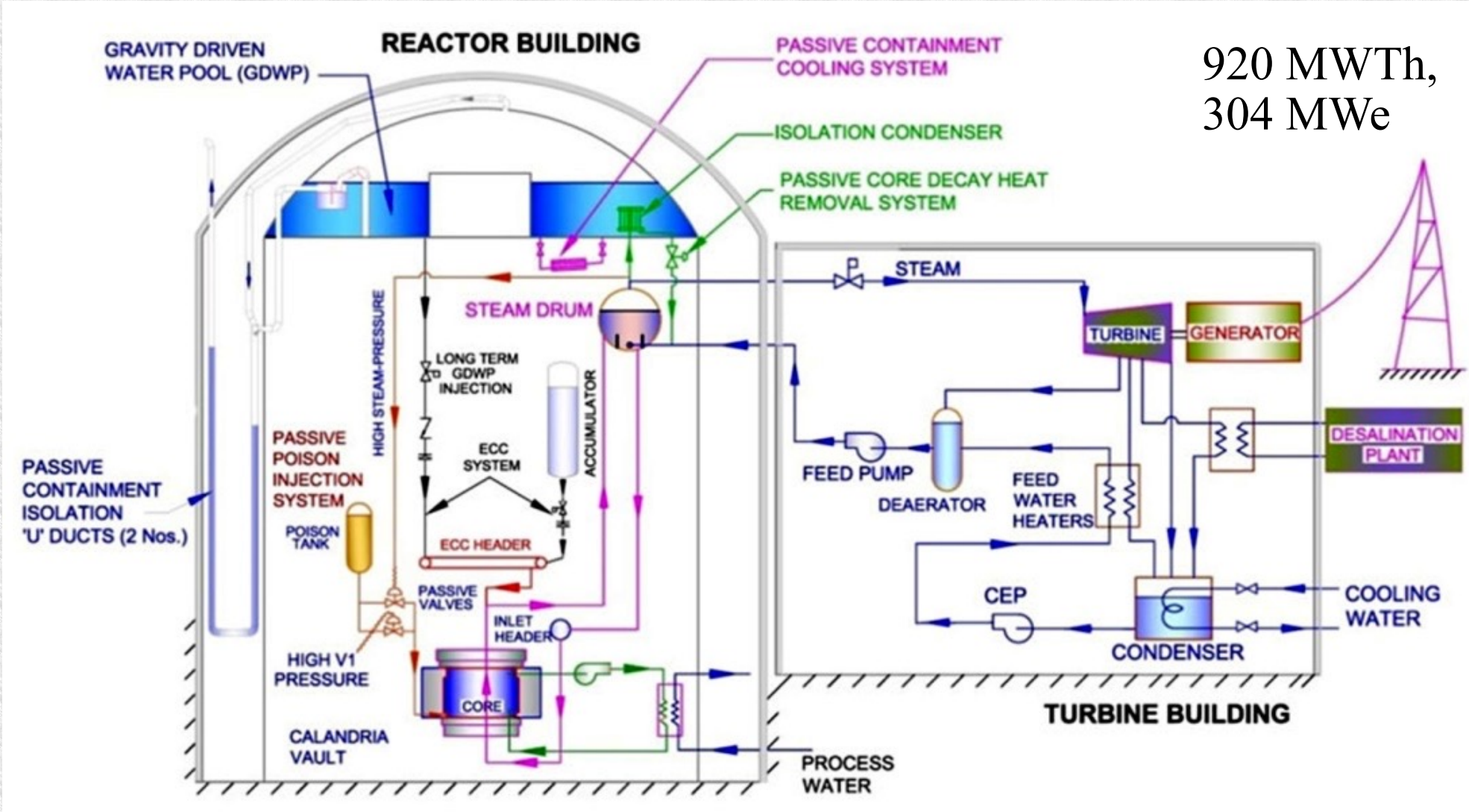
^{99m}Tc generators.

Radioactive needles, tubes or seeds of isotopes like ^{137}Cs, ^{198}Au and ^{192}Ir for intra-cavitary and interstitial treatment for certain cancers.
^{137}Cs and ^{192}Ir brachytherapy sources.

Fast Breeder Test Reactor, I.G.C.A.R., Kalpakkam

Core loading of 500 MWe FBR reactor at Kalpakkam was done on 4 March, 2024.

Advanced Heavy Water Reactor (AHWR)

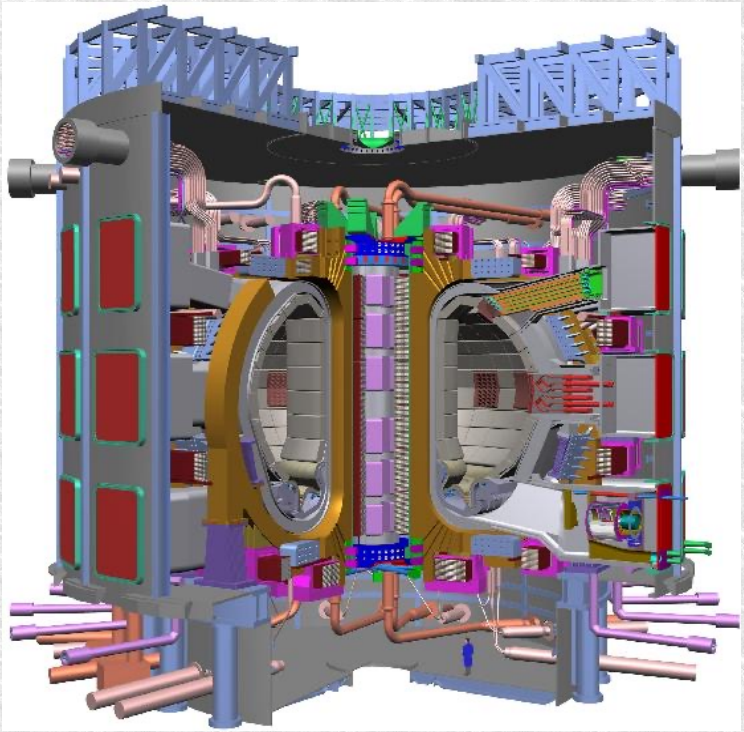


For early Th utilisation. Desalination using waste heat.

BARC Newsletter, Jan-Feb 2021, N. K. Maheshwari, M. T. Kamble, V. Shivakumar, Umasankari Kannan, A. K. Nayak and Avaneesh Sharma

Fusion Reactors

$$D + T \rightarrow He + n + 17.6MeV$$



Superconducting Steady-State TOKAMAK at IPR

ITER: International Thermonuclear Experimental Reactor

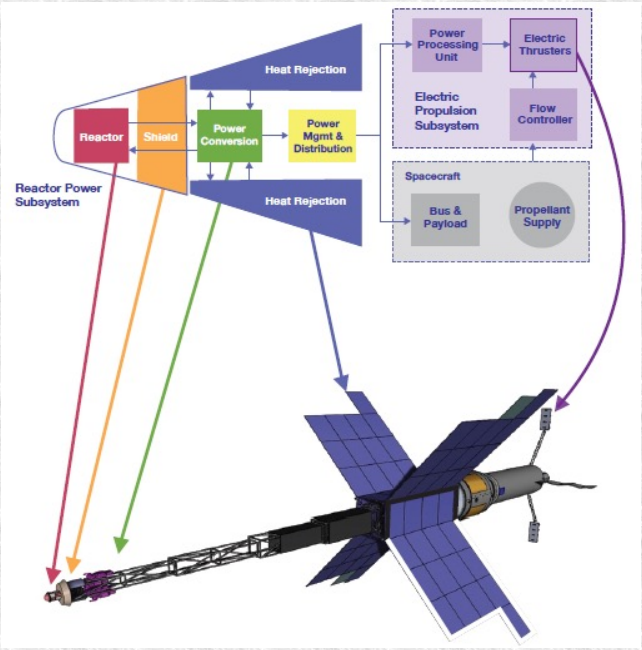
European Union (EU), India, Japan, China, Russia, South Korea and the United States

Nuclear Energy in Propulsion

Space

Photo of a nuclear thermal propulsion (NTP) system from the Rover/Nuclear Engine for Rocket Vehicle Applications programs).

SOURCE: M. Houts, et al., "NASA's Nuclear Thermal Propulsion Project," NASA Marshall Space Flight Center, 2018, ntrs.nasa.gov/citations/20180006514.



Nuclear electric propulsion subsystems and conceptual design.

SOURCE: Briefing to the committee by Lee Mason, NASA, June 8, 2020.

ISRO is using two Radioisotope Heating Units (RHUs) in Chandrayaan-3.

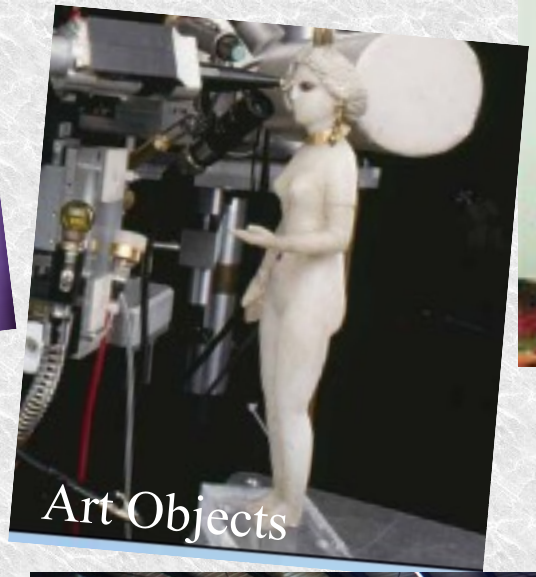
ISRO is developing a 100-watt Radioisotope Thermoelectric Generator (RTG) in future missions.

ISRO is developing a NTP rocket engine in collaboration with the Bhabha Atomic Research Center (BARC) using isotopes like strontium-90 and plutonium-238.

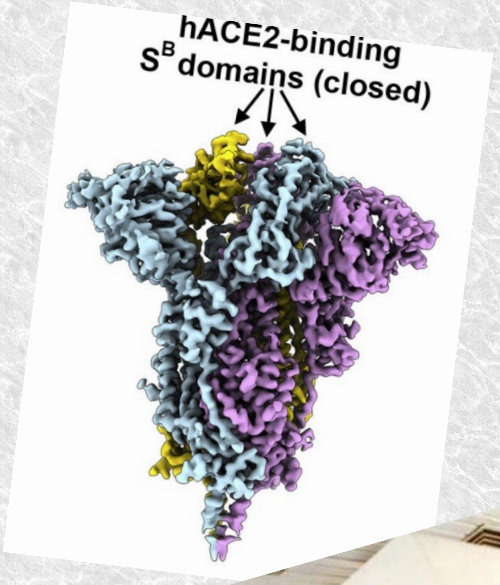
Sea

Indian Navy's *Arihant* (6000 dwt) SSBN has an 82.5 MWe PWR using 40% enriched uranium driving the submarine. The reactor went critical in August 2013. Arighat, a variant of *Arihant* has also joined the fleet. Further vessels in the class are expected to have a 100 MWt PWR reactor.


Heart Valve

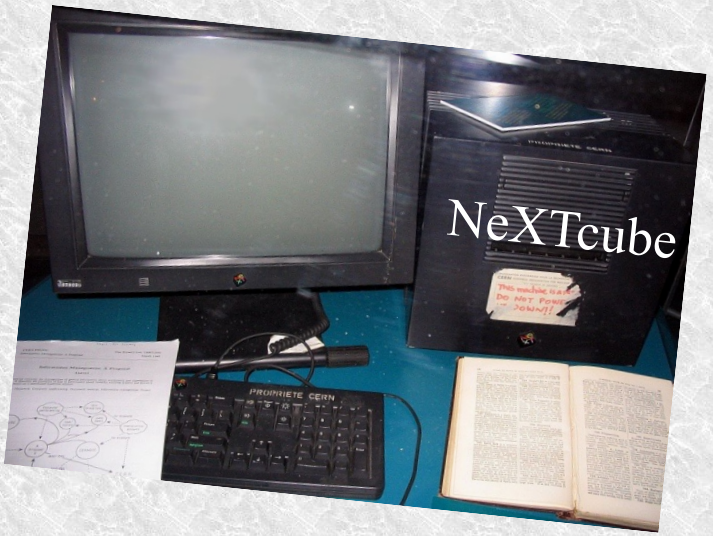

Art Objects


Diapers


hACE2-binding
S^B domains (closed)


Cargo Inspection


Medical
Supplies


NeXTcube

Summary

Many ingenious applications of radioisotopes and radiation.

Nuclear Science and Technology has deeply impacted many aspects of our life.

Nuclear power is essential for mitigating Climate change effects and sustainable development.

The remnants of nuclear reactors nearly two billion years old were found in the 1970s at Oklo mines, in Gabon, Africa.