

Neutron Source and Research Applications

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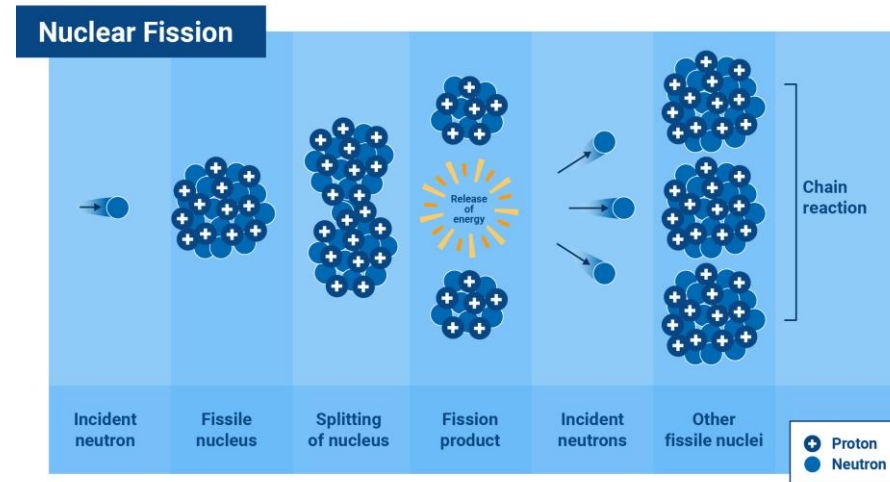
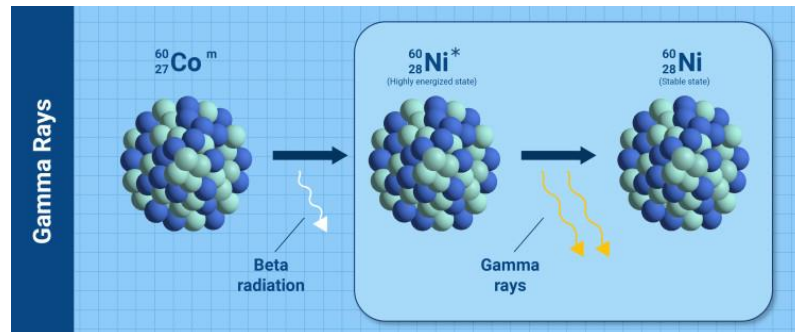
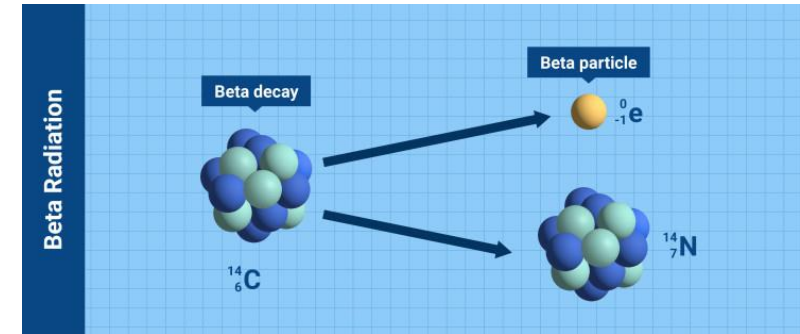
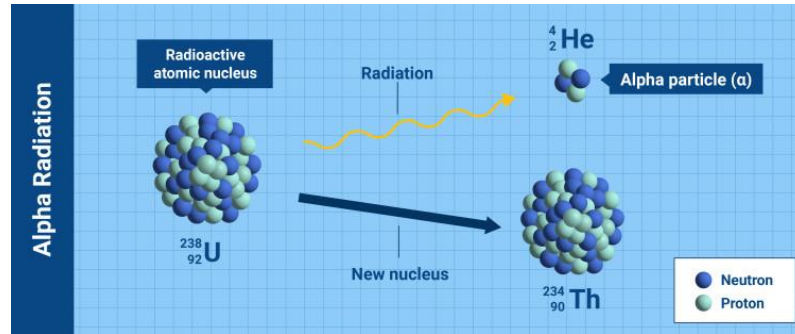
Introduction to Neutron sources

Interaction of neutrons with matter

Neutron Irradiations of various samples

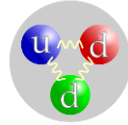
Neutron Activation Analysis

Radiation sources & Types

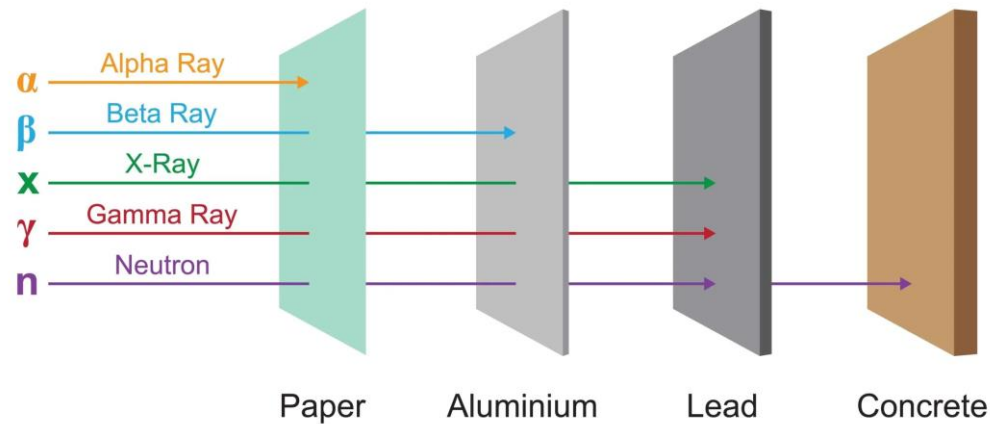


Why they are special.?

Neutrons



Penetrating Power of Different Types of Radiation

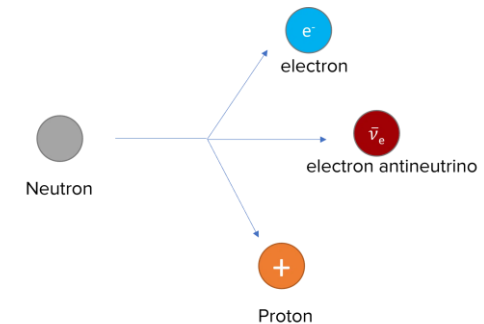


Energy Range: <0.0001 eV (cold neutrons) to >20 MeV (high-energy neutrons)

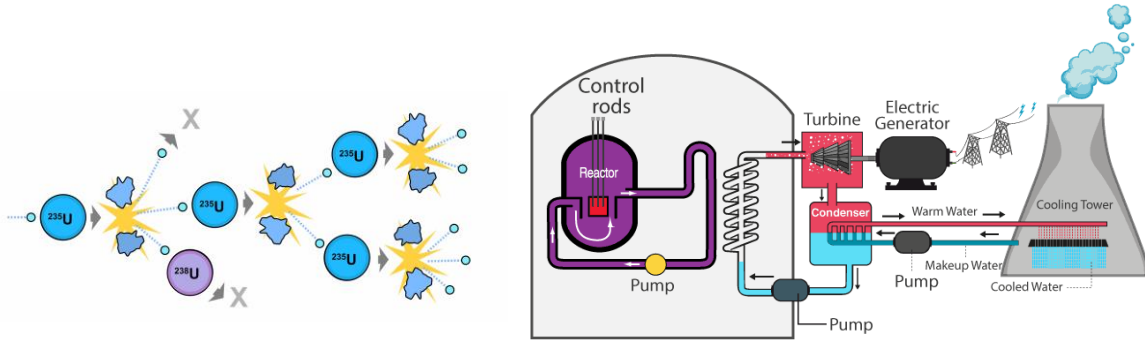
Cold neutrons < 0.003 eV
Slow (thermal) neutrons 0.003 – 0.4 eV
Slow (epithermal) neutrons 0.4 – 100 eV
Intermediate neutrons 100 eV– 200 keV
Fast neutrons 200 keV– 10 MeV
High energy (relativistic) neutrons > 10 MeV

Slow (thermal) neutrons 0.003 – 0.4 eV
(2.2 km/s)

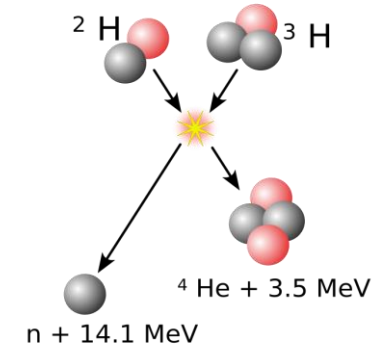
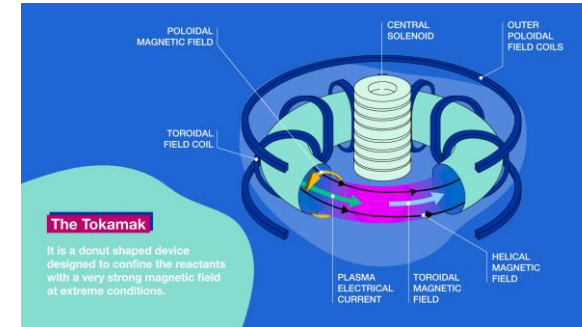
Mean life-time:
 877.75 ± 0.28 sec



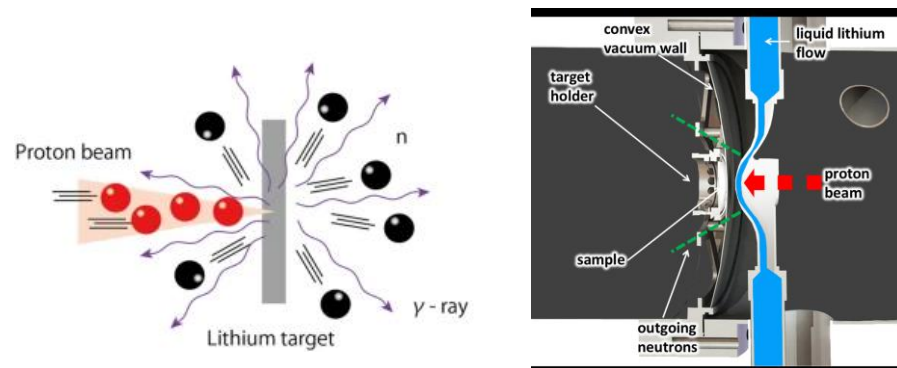
How to produce neutrons



Nuclear Reactor-Based Sources



Fusion-Based Neutron Sources



Accelerator-Based Neutron Sources
 $\text{Li} + \text{p} \rightarrow \text{Be} + \text{n}$

AmBe
Americium Beryllium



Radioisotope Based neutron Source

Neutron source Facility, MAHE, Manipal

Irradiation chamber

Source room

Neutron source facility

Bhabha Atomic Research

Few images removed

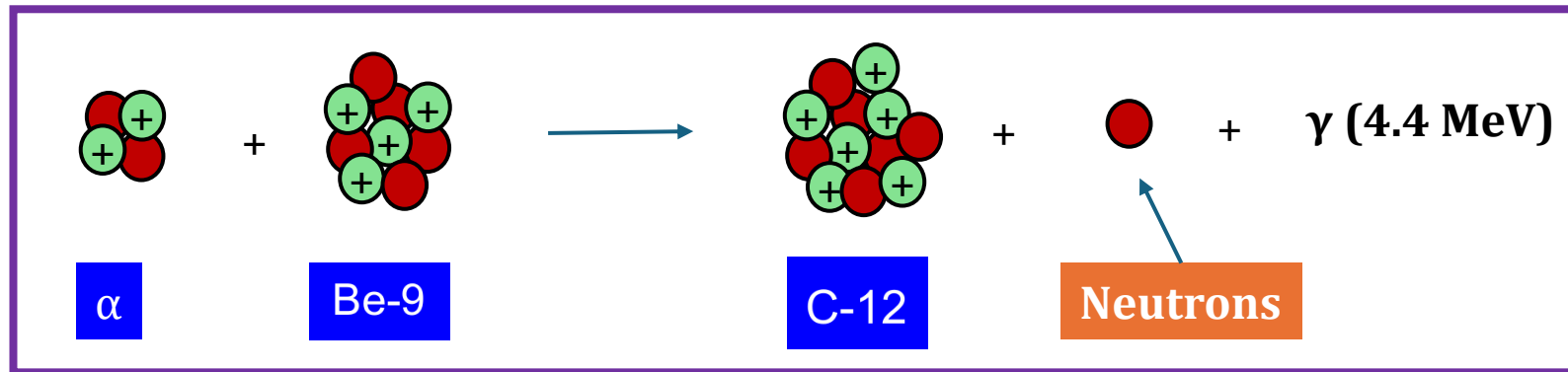
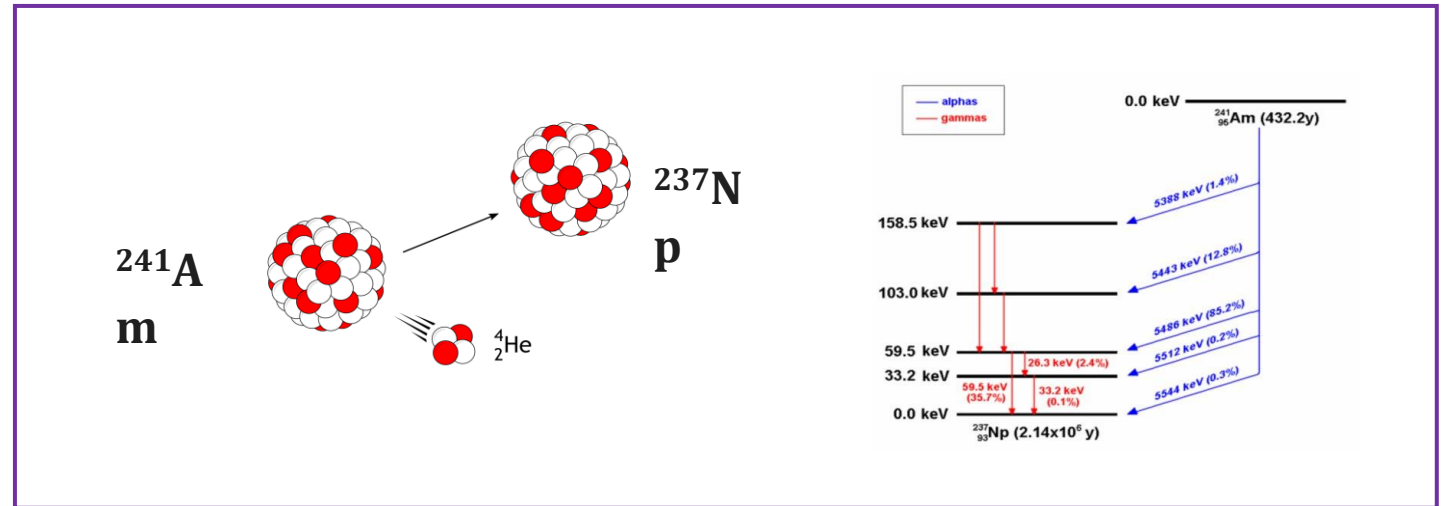


Dr. K. V. Subbaiah, MCNS, Manipal

How to produce neutrons

Radioisotope-Based Sources - These rely on spontaneous neutron emission from radioactive materials.

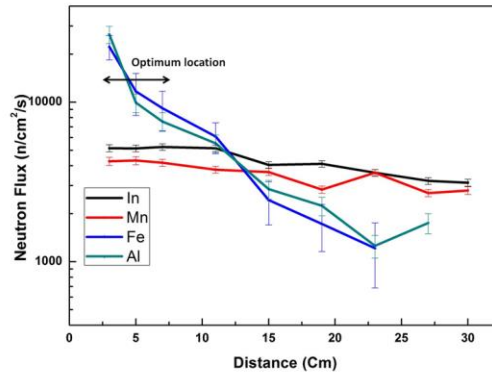
Americium Beryllium Neutron source



Neutron source Facility, MAHE, Manipal



16 Curie Radioisotopes of **Am-241**
 $16 \times 3.7 \times 10^{10}$

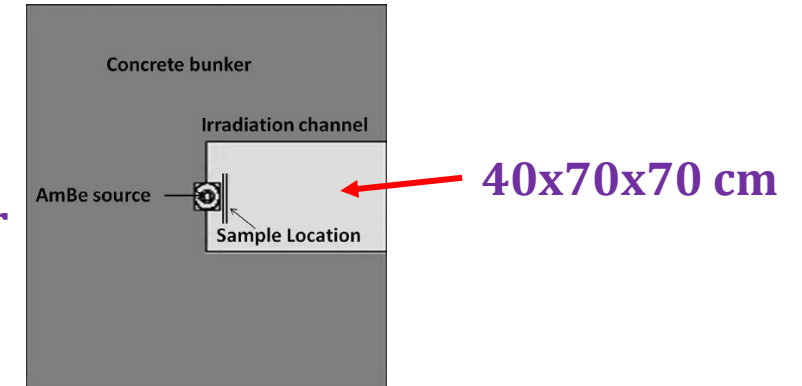


Spatial neutron flux mapping

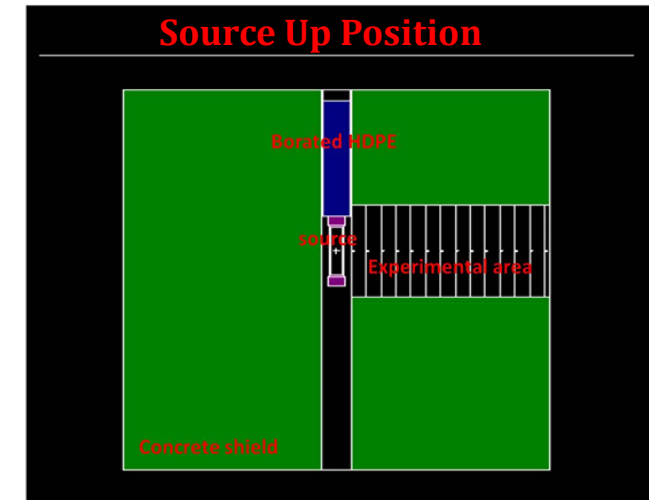
At 5 cm in our irradiation facility, we have flux around,
 10^4 neutron/cm²/second

neutron housing schematic

1.5 x 1.5 x 1.3 m
Concrete bunker

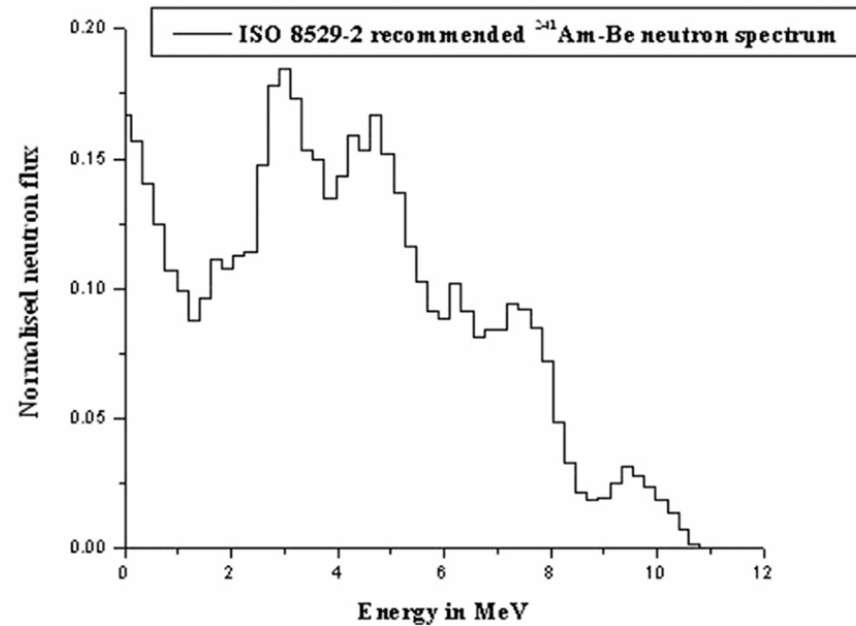


Source Up Position

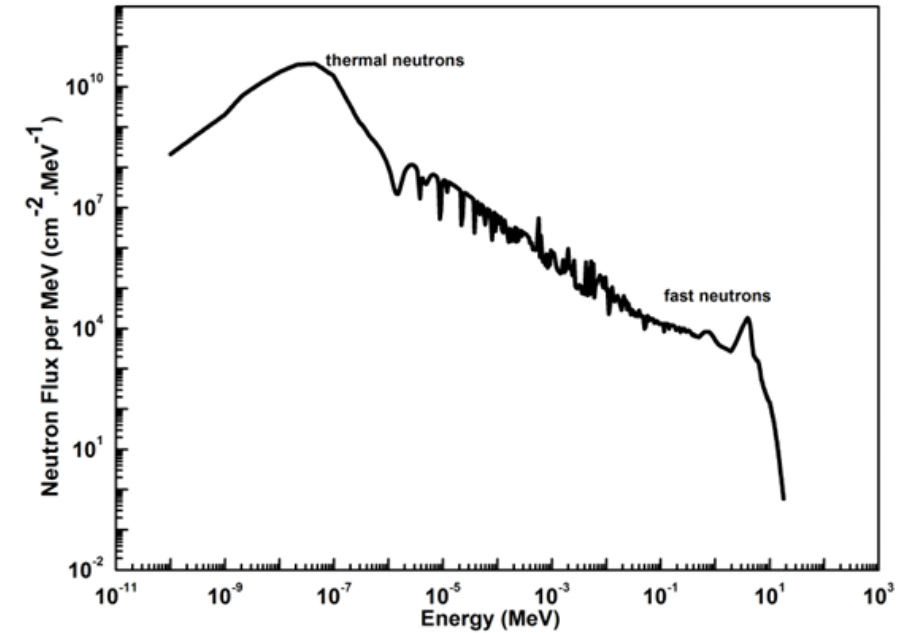
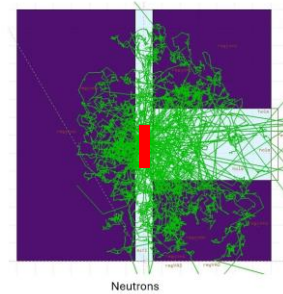


Neutron Yield = 3.5×10^7 neutrons/sec

Neutron source Facility, MAHE, Manipal

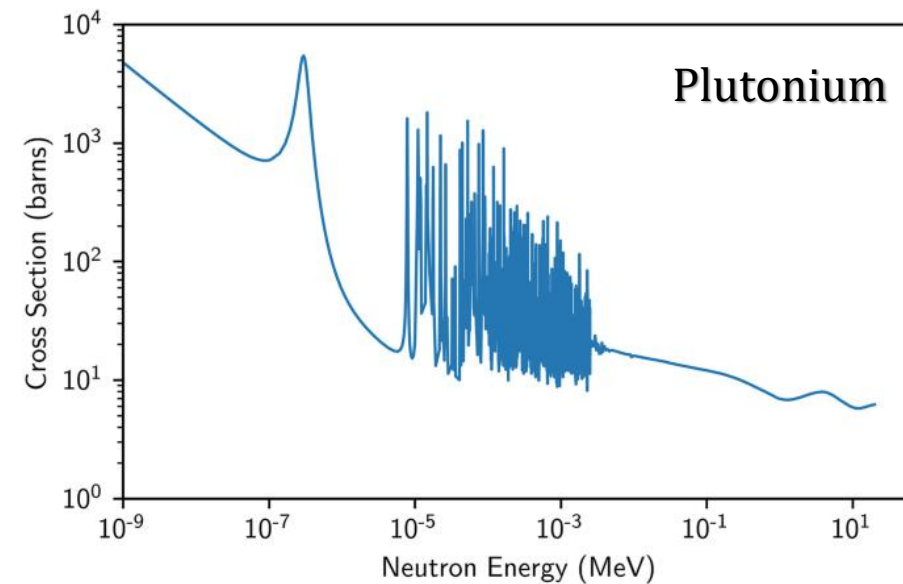
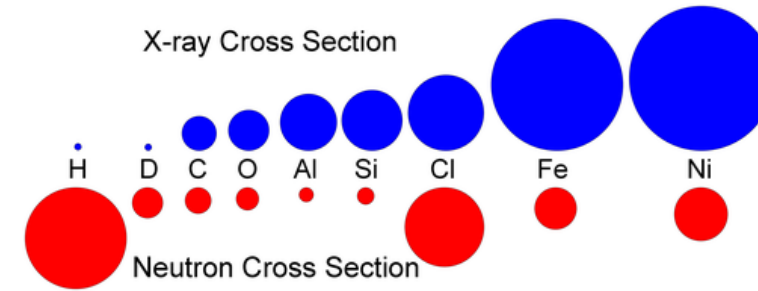
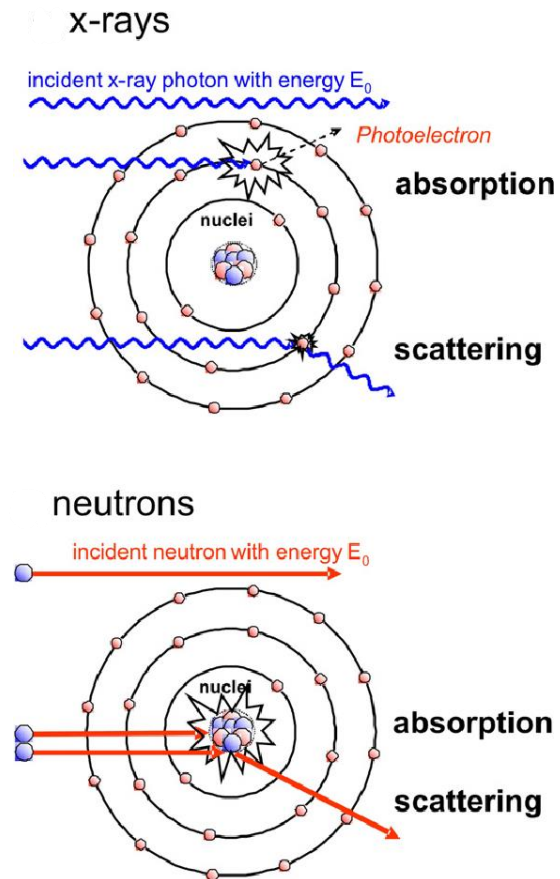


AmBe ISO-8529 spectrum



Spectra at irradiation location

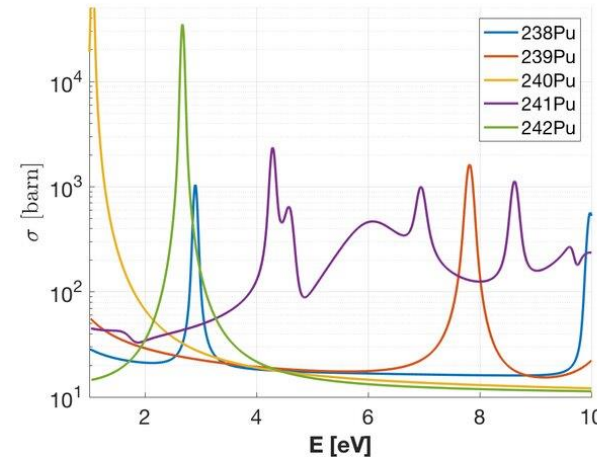
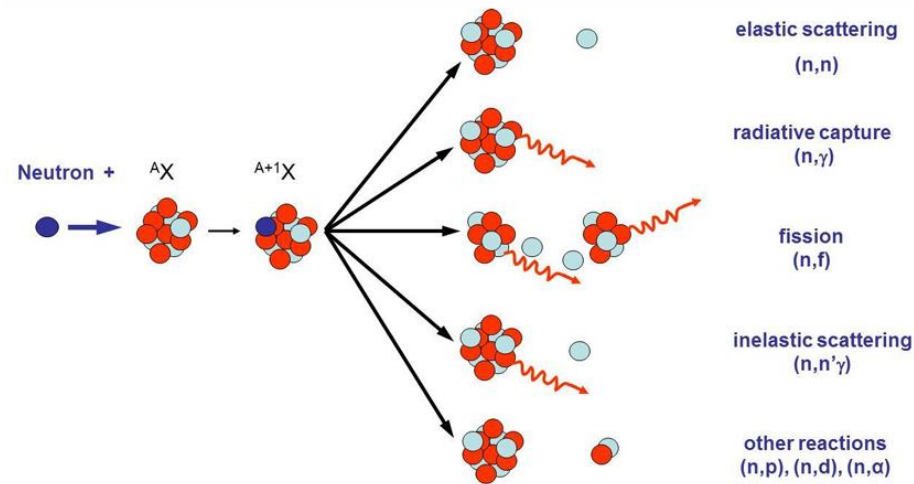
Neutron interaction with Atomic Nucleus



Neutron Cross section (Interaction probability)
varies with incoming neutron energy

Neutron interaction with Atomic Nucleus

Neutron Cross section (Interaction probability) varies with incoming neutron energy



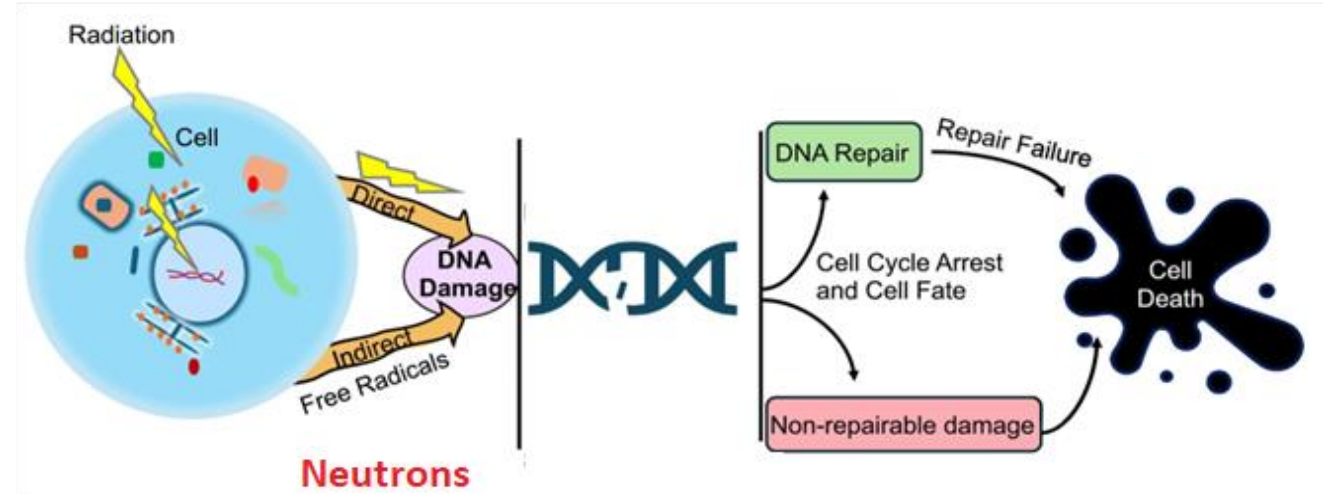
Total interaction cross sections for epithermal neutrons for various plutonium isotopes

Scientific Research | Medical Applications
Industrial Uses | Security, Detection & Defence

Biological Effects



Neutron source



DNA Damage & Mutations

Neutron irradiation of water in cells produces **free radicals** (OH , H , O_2), which cause oxidative stress and DNA damage.

Cell Death High neutron doses trigger programmed cell death

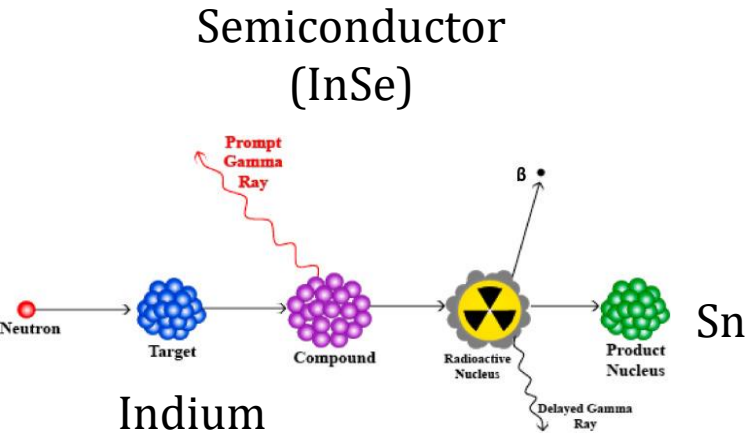
Changes in Cell Cycle

Neutron irradiation alters cell division rates, leading to delayed growth or uncontrolled proliferation (cancer risk).

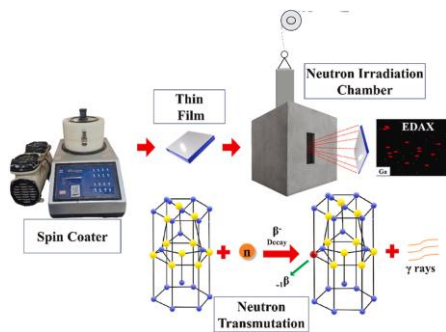
Inducing genetic mutations for crop improvement.

Mutation Breeding in Plants

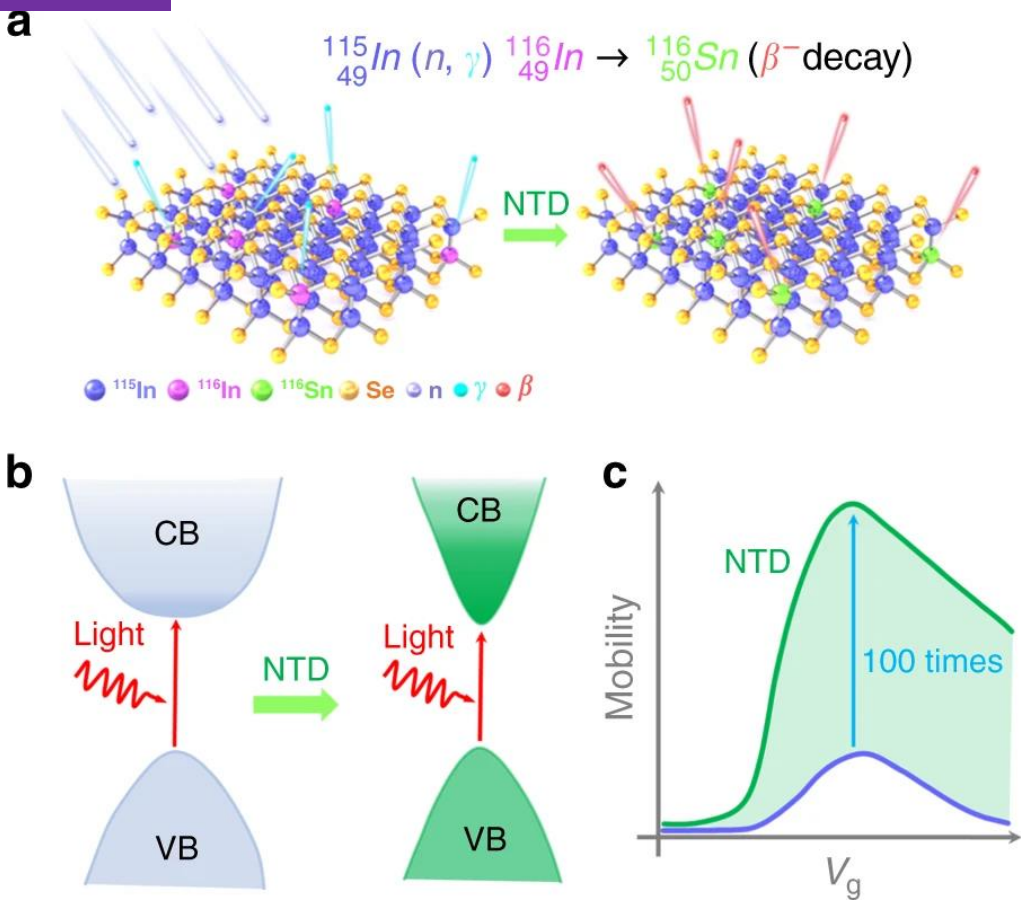
Neutron transmutation doping (NTD)



Modifying electrical and optical properties



<http://dx.doi.org/10.1016/j.ceramint.2024.11.252>



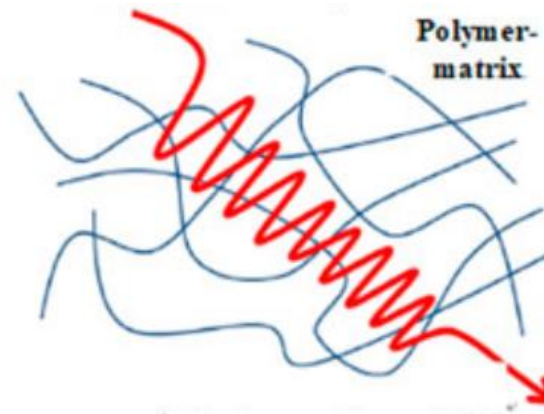
a Transmutation neutron doping (NTD) scheme for 2D layered InSe, including the capture of thermal neutrons and decay of γ and β^- particles. b, c Energy band structures and mobility in 2D layered InSe before and after transmutation neutron doping. CB and VB represent the conduction band and valence band, respectively

Article: “Clean” doping to advance 2D material phototransistors

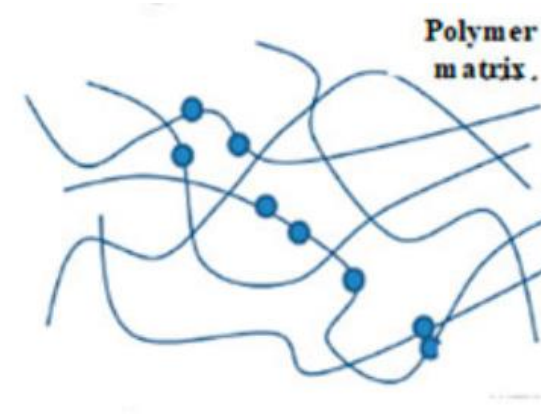
<https://www.nature.com/articles/s41277-022-00842-4>

Neutron induced molecular changes

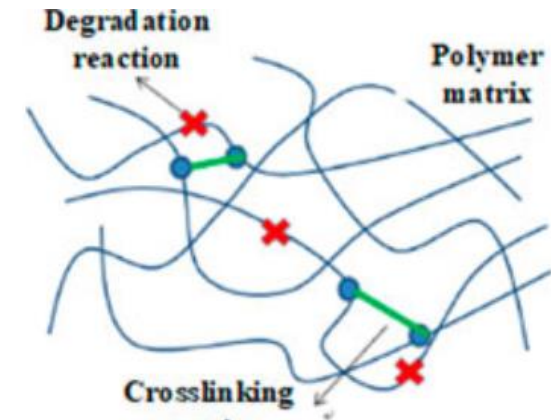
Neutron irradiation can break chemical bonds and create free radicals. This affects properties of polymers.



a) interaction of radiation with material



b) Production of free radicals



c) Chemical reaction



Radiation Physics and Chemistry
Volume 218, May 2024, 111590



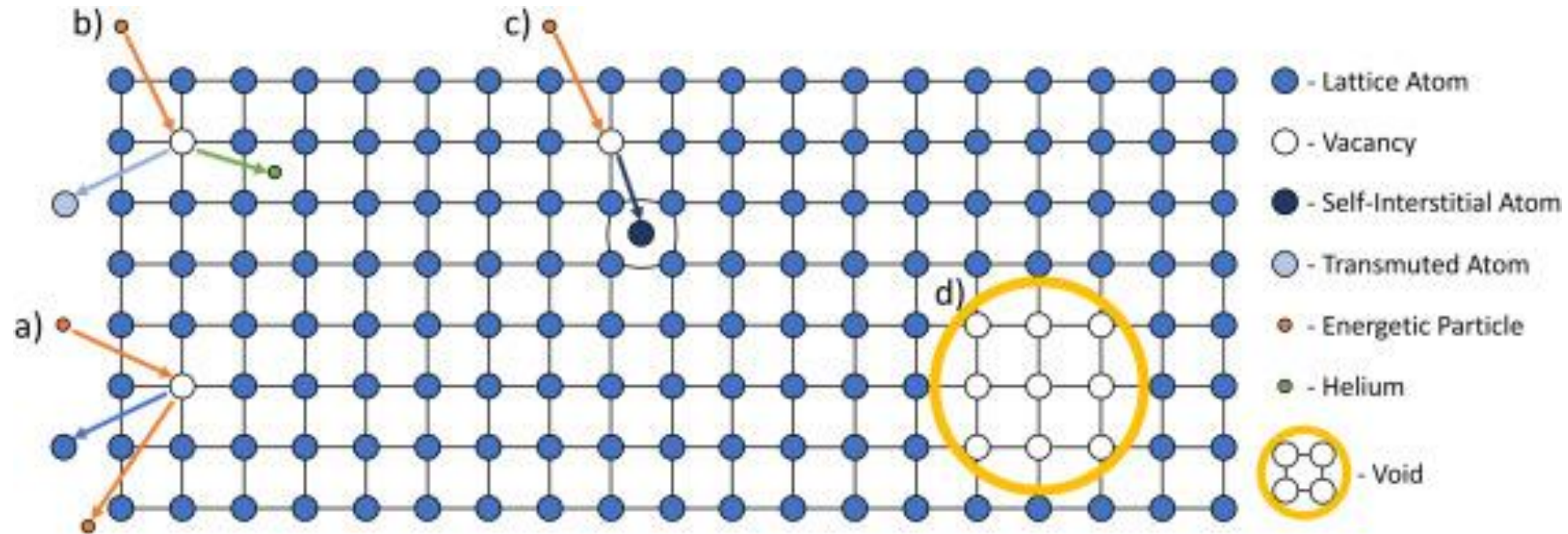
A novel approach to enhance the ionic conductivity of silver nanoparticles incorporated PVA:NaBr polymer electrolyte films via fast neutron irradiation

M.P. Shilpa ^a, Vipin Cyriac ^b, S.C. Gurumurthy ^a, , Ismayil ^b, Sachin Shet ^c, K.V. Subbaiah ^c, M.S. Murari ^d

<https://doi.org/10.1016/j.radphyschem.2024.11159>

Lattice Defects & Displacement Damage

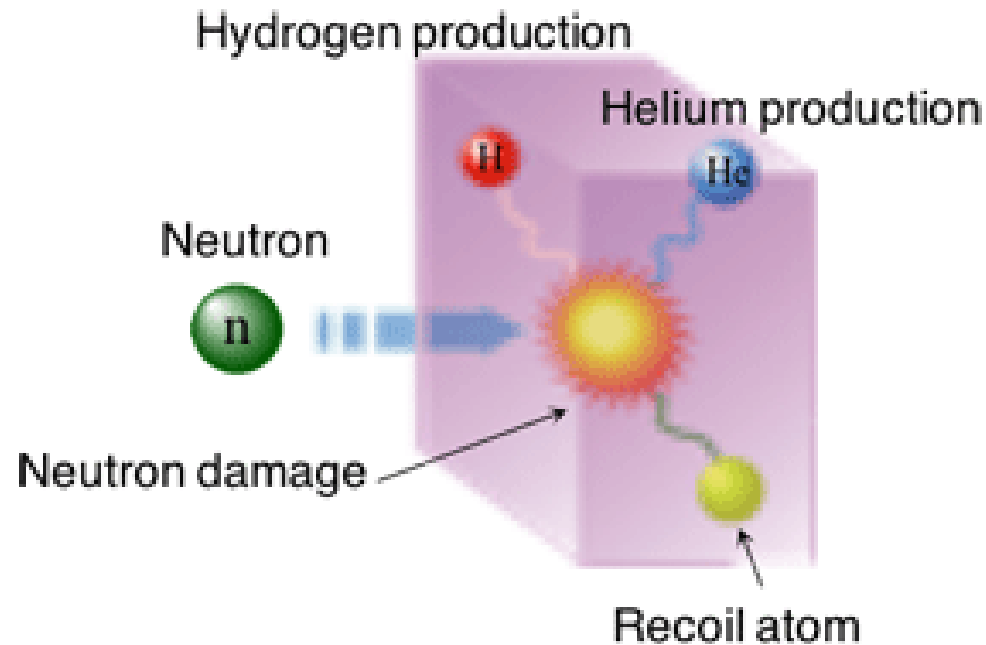
Neutrons displace atoms, creating defects in crystal structures, which Alters electrical, mechanical, and optical properties of materials.



A schematic showing some of the defects caused by irradiation: a) an energetic particle (such as a neutron) collides with a lattice atom resulting in its ejection, b) an energetic particle collides with a lattice atom in a transmutation reaction resulting in a transmuted atom, a vacancy, and helium, c) an energetic particle collides with a lattice atom resulting in its displacement forming a vacancy and a self-interstitial, and d) a cluster of vacancies forming a void.

<https://doi.org/10.1016/B978-0-12-822944-6.00044-X>

Gas production inside materials by neutrons



**Nuclear Environments
Defence and Security
Space Exploration**

Stainless Steel (e.g., 316 SS): Nickel and iron undergo (n, p) and (n, α) , producing H and He.

Zirconium Alloys (e.g., Zircaloy): Used in fuel cladding; less prone but still generates gas from trace impurities.

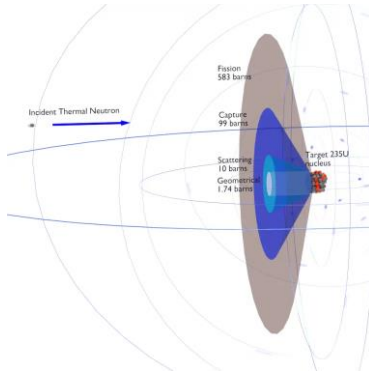
(n, α) Reactions A neutron is absorbed, and an alpha particle (helium nucleus) is emitted.

Common in: Boron (e.g., in control rods or impurities), nitrogen, or oxygen.

(n, p) Reactions A neutron hits a nucleus, ejecting a proton and leaving a new isotope.

Common in: Nickel, iron, or other metals in alloys.

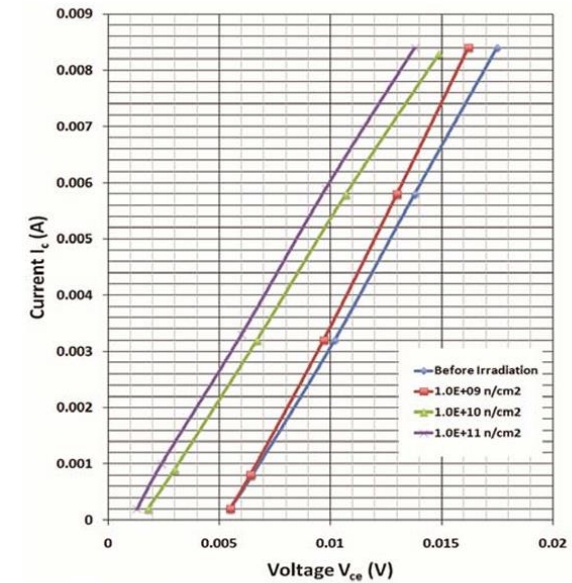
Research applications



Neutron cross section measurement

Optical fiber

Solar cell



I-V characteristics of transistor BC547

Neutron irradiation of IC

Ref: (PDF) [Experimental study of neutron irradiation effect on elementary semiconductor devices using Am-Be neutron source](#)

NAA

Neutron Capture Which produces radioisotope in the sample, this can be used as a tool to investigate elemental composition

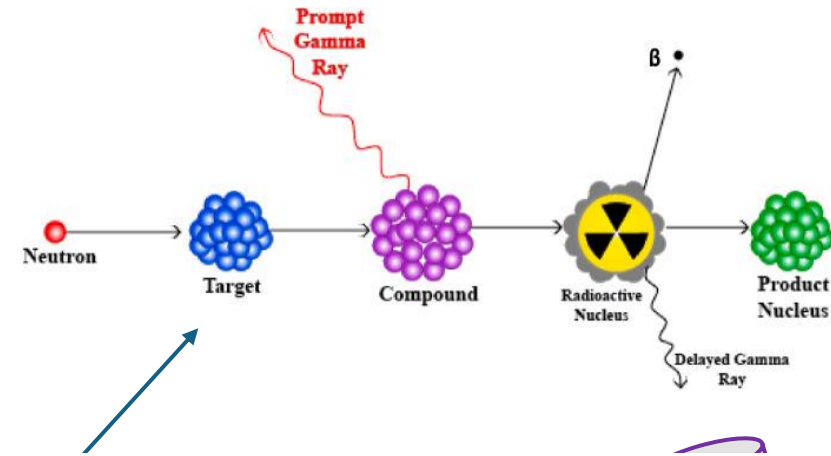
$$A = N \sigma \phi (1 - e^{-\lambda t_i})$$

$$C = \Delta N \gamma \epsilon = \Phi_{th} \sigma_{eff} \frac{N_{Au} \theta m_x}{M_a} (1 - e^{-\lambda t_i}) e^{-\lambda t_d} \frac{(1 - e^{-\lambda t_m})}{\lambda} \Gamma \epsilon$$

Φ = neutron flux

λ = decay constant of produced isotope

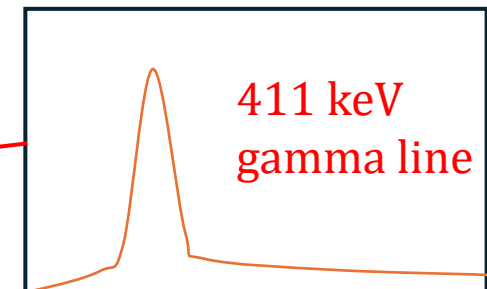
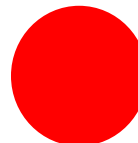
t_i = Irradiation time



Au - 197



Au - 198



Applications

Non-destructive material analysis: Determining the elemental composition of materials without damaging them

Quality control: Ensuring the purity

Archaeology & Cultural Heritage:

Elemental analysis of biological samples

Neutron cross section measurement

Art Authentication - analyzing pigment or material composition

What can be done with neutron..?

Neutron irradiation to enhance material properties

Neutron irradiation check material behavior in radiation fields

Sample's elemental analysis with Neutron activation

Radiation hardness

Biological sample – mutation, cell damage and repair

Neutron shielding

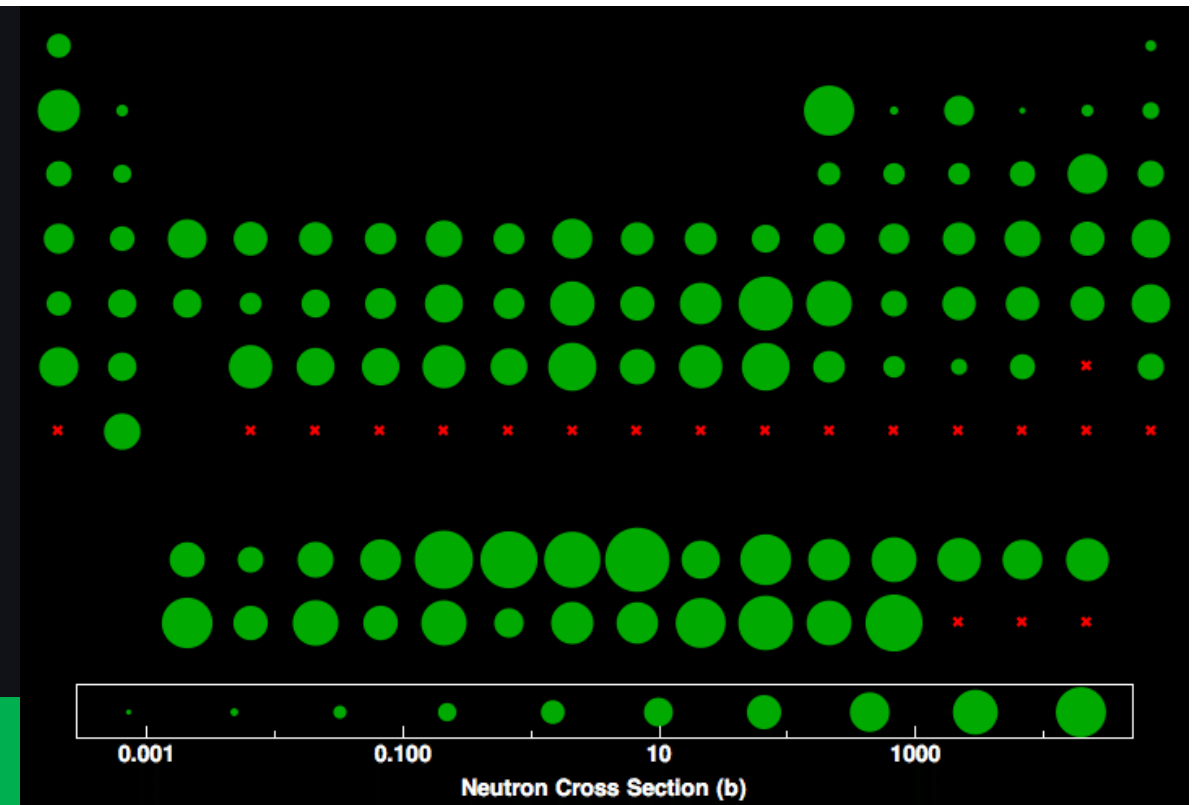
MANY MORE.....

Neutron Irradiation on + “Research Domain”

Search

1	H	Hydrogen	2	He	Helium
3	Li	Lithium	4	Be	Beryllium
11	Na	Sodium	12	Mg	Magnesium
19	K	Potassium	20	Ca	Calcium
21	Sc	Scandium	22	Ti	Titanium
23	V	Vanadium	24	Cr	Chromium
25	Mn	Manganese	26	Fe	Iron
27	Co	Cobalt	28	Ni	Nickel
29	Cu	Copper	30	Zn	Zinc
31	Ga	Gallium	32	Ge	Germanium
33	As	Arsenic	34	Se	Selenium
35	Br	Bromine	36	Kr	Krypton
37	Rb	Rubidium	38	Sr	Strontium
39	Y	Yttrium	40	Zr	Zirconium
41	Nb	Niobium	42	Mo	Molybdenum
43	Tc	Technetium	44	Ru	Ruthenium
45	Rh	Rhodium	46	Pd	Palladium
47	Ag	Silver	48	Cd	Cadmium
49	In	Indium	50	Sn	Tin
51	Sb	Antimony	52	Te	Tellurium
53	I	Iodine	54	Xe	Xenon
55	Cs	Caesium	56	Ba	Barium
57	La	Lanthanum	58	Ce	Cerium
59	Pr	Praseodymium	60	Nd	Neodymium
61	Pm	Promethium	62	Sm	Samarium
63	Eu	Europium	64	Gd	Gadolinium
65	Tb	Terbium	66	Dy	Dysprosium
67	Ho	Holmium	68	Er	Erbium
69	Tm	Thulium	70	Yb	Ytterbium
71	Lu	Lutetium	72	Hf	Hafnium
73	Ta	Tantalum	74	W	Tungsten
75	Re	Rhenium	76	Os	Osmium
77	Ir	Iridium	78	Pt	Platinum
79	Au	Gold	80	Hg	Mercury
81	Tl	Thallium	82	Pb	Lead
83	Bi	Bismuth	84	Po	Polonium
85	At	Astatine	86	Rn	Radon
87	Fr	Francium	88	Ra	Radium
89	Ac	Actinium	90	Th	Thorium
91	Pa	Protactinium	92	U	Uranium
93	Np	Neptunium	94	Pu	Plutonium
95	Am	Americium	96	Cm	Curium
97	Bk	Berkelium	98	Cf	Californium
99	Es	Einsteinium	100	Fm	Fermium
101	Md	Mendelevium	102	No	Nobelium
103	Lr	Lawrencium	104	Rf	Rutherfordium
105	Db	Dubnium	106	Sg	Seaborgium
107	Bh	Bohrium	108	Hs	Hassium
109	Mt	Meitnerium	110	Ds	Darmstadtium
111	Rg	Roentgenium	112	Cn	Copernicium
113	Nh	Nihonium	114	Fl	Flerovium
115	Mc	Moscovium	116	Lv	Livermorium
117	Ts	Tennessium	118	Og	Oganesson

Neutron Cross Section



Thank You...,

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