Yerevan Physics Institute

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The Possibility of Obtaining Intense Neutron Source on the base of proton Cyclotron C18.
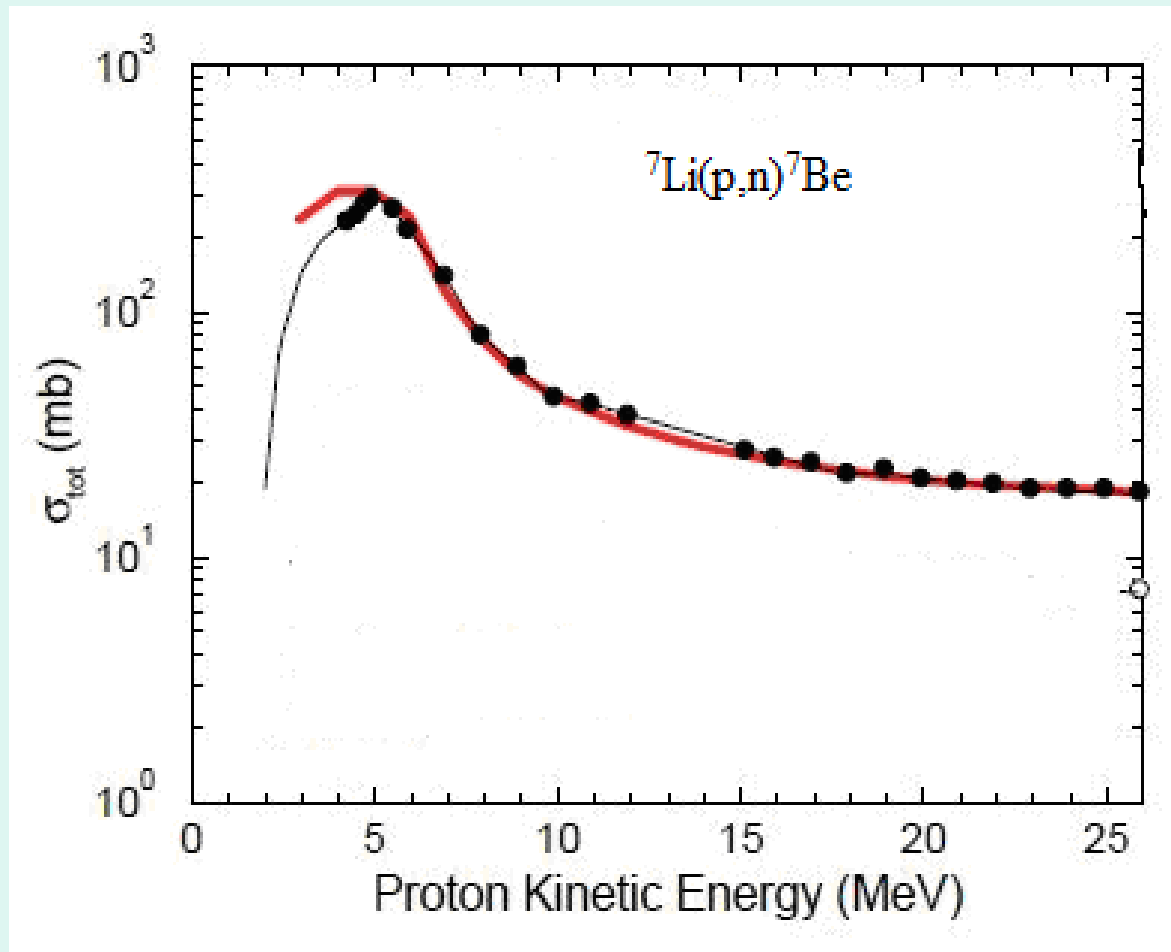*New Accelerator Complex for Science and Application.*
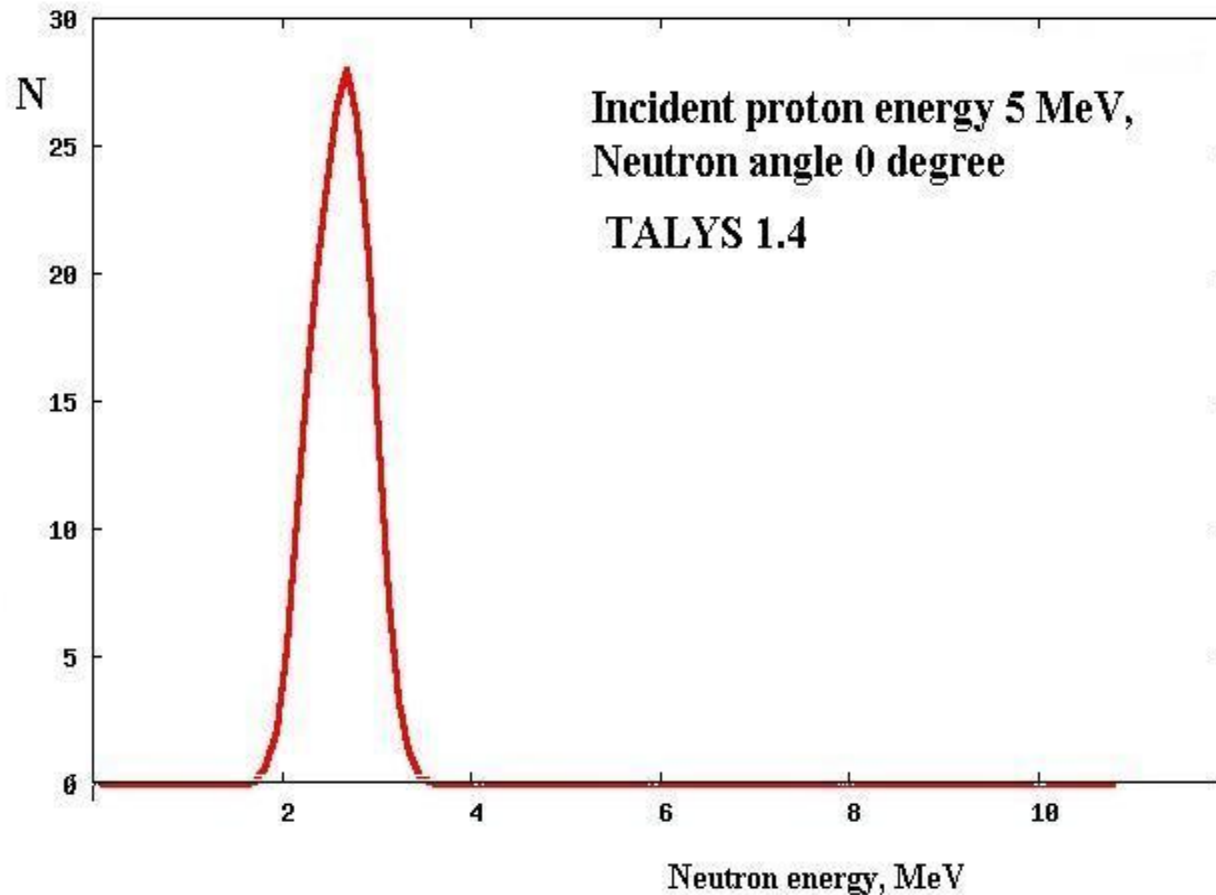
General view of CYCLONE C18/18

The technical features of CYCLONE C18/18 :
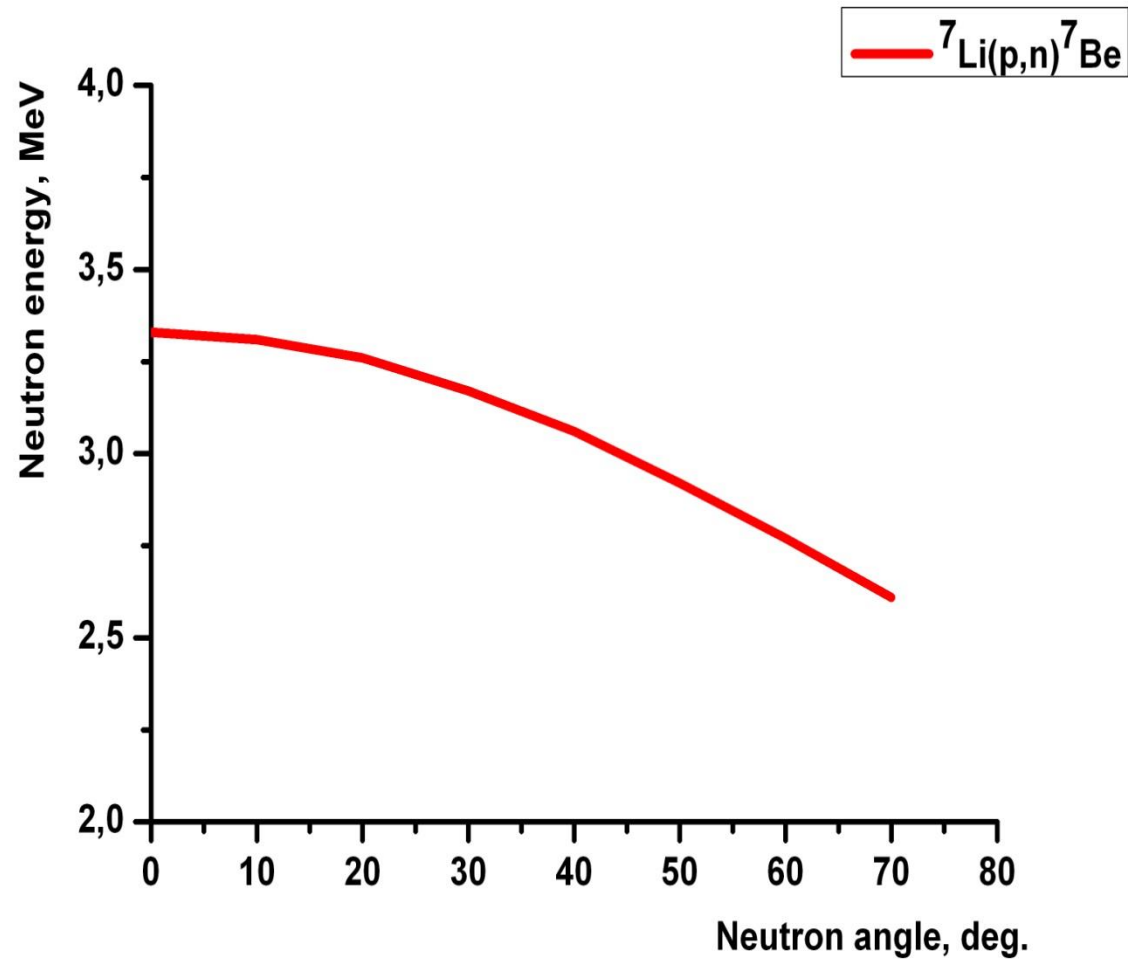
- *Energy proton*   *18 MeV*

- *Beam current proton*
  High current (HC):   *150 µA*
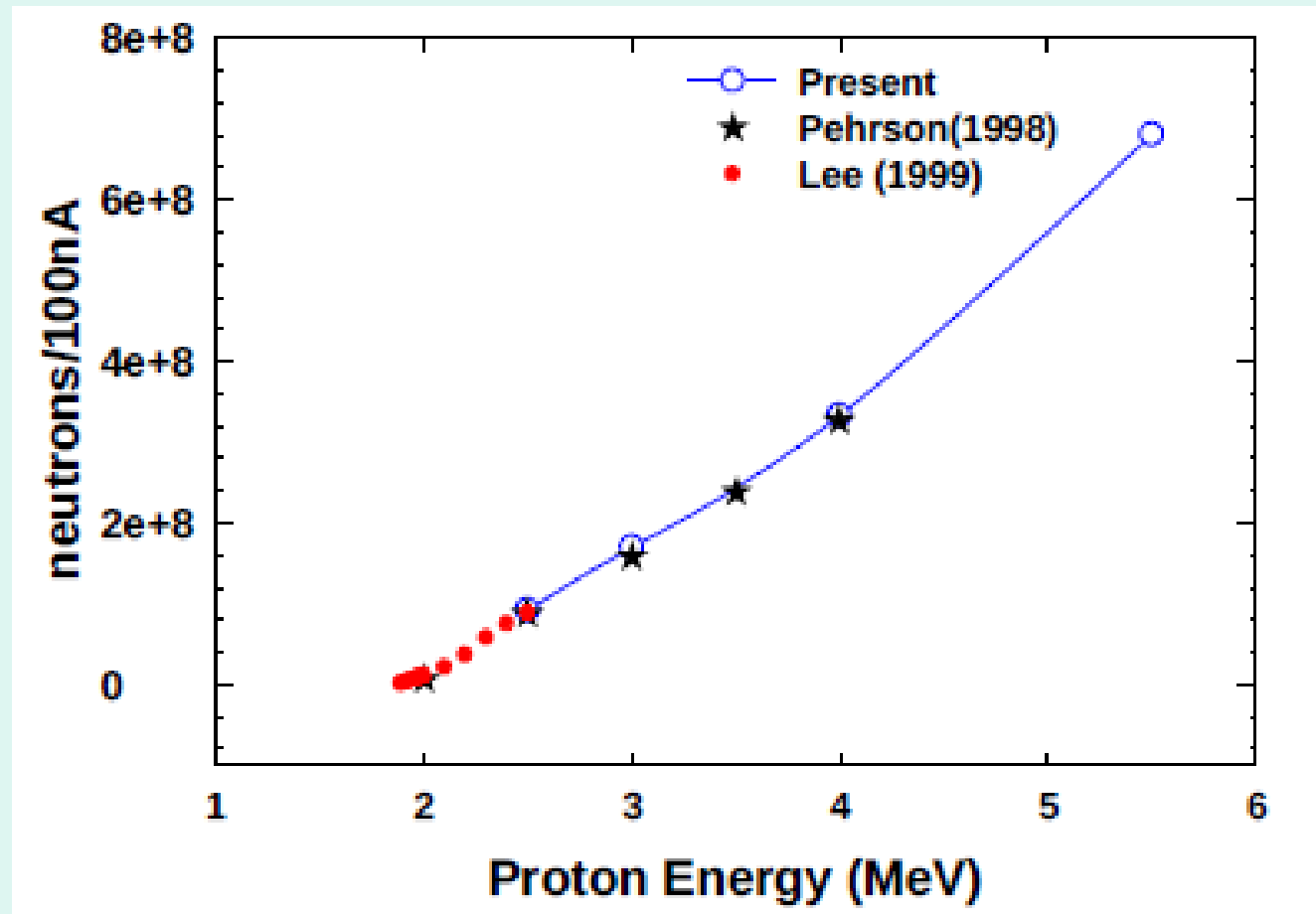 *Standard (ST):*   *100 µA*

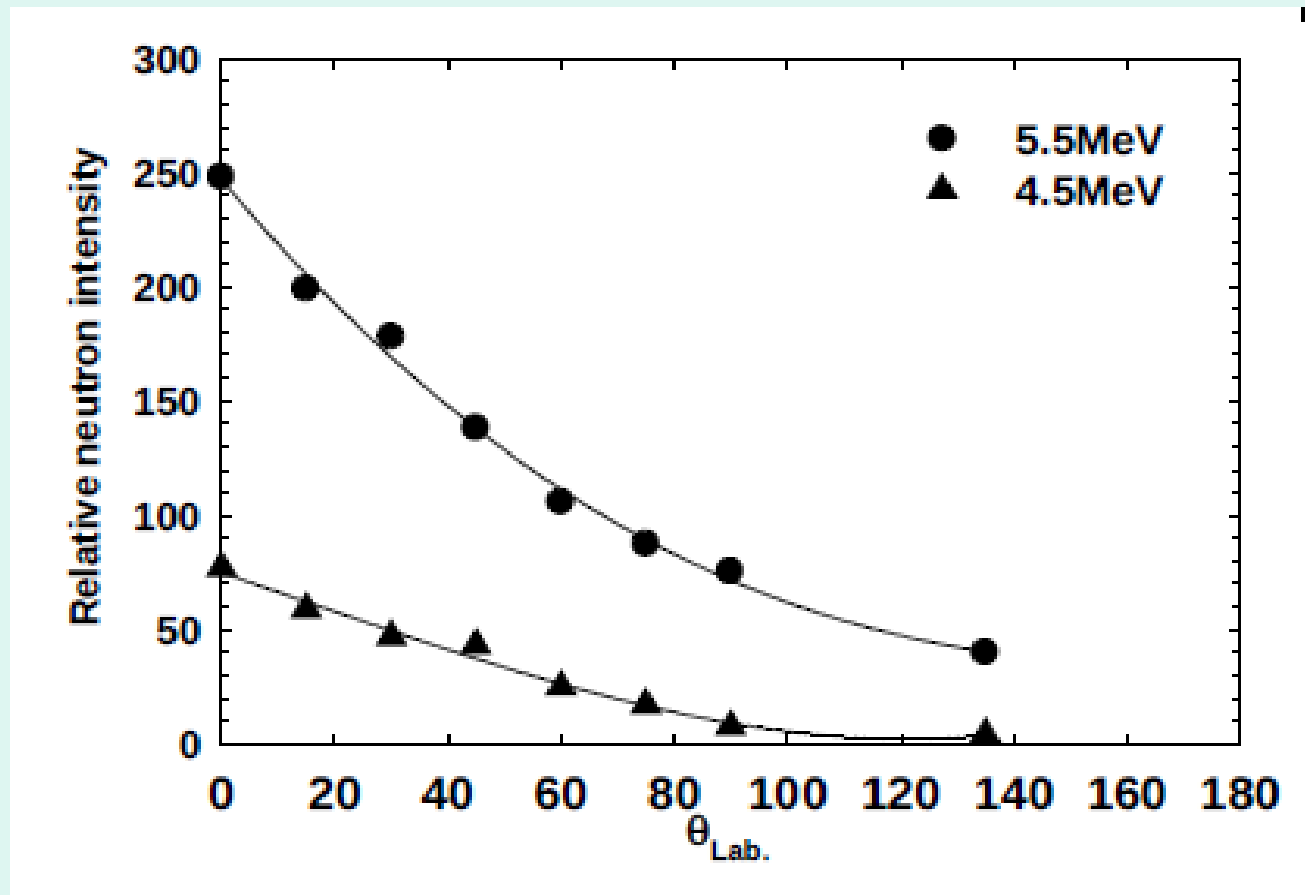*The dependence of cross section via incident proton energy*

The spectra of emitted neutrons at incident protons energy 5 MeV

The angular-energy dependence of emitted neutrons at incident protons energy 5 MeV

Neutron yield from a 5mm thick natural Lithium target for proton energies from 2.5 to 5.5 MeV

Angular distribution of neutron yield from thick Lithium target from 4.5 and 5.5 MeV proton energies

Thus, on the based on the preliminary calculations could be confirmed that on the external proton beam of the cyclotron C18 it is possible to obtain neutron beam with intensity $1.43*10^7$ n /cm^2·sec in the forward direction for basic and applied investigations.

However the received intensity is about 2 order of magnitude low than is necessary for basic science, applied physics and, particular, for BNCT (10^9 n/cm^2·sec).

For BNCT is suitable the accelerator with energy 5 MeV and intensity 50 mA. This technology is not exist yet.

For BNCT could be used the produced by IBA cyclotron C30-70 with energy 30-70 MeV and intensity 1.0-1.5 mA.

A new accelerator complex is proposed to build at AANL which will provide large scientific investigations program in nuclear physics and nuclear astrophysics.

Complex based on cyclotron C30 or C70 will provide more effective neutron therapies (Boron Neutron Capture Therapy) for treatment of patients with malignant form of cancer diseases which is not available for any other form of therapy. The new complex will provide a variety of clinically interesting technologies for treating patients as well as clinical studies.

Nuclear Structure:

- *Explore the limits of existence and study new phenomena;*

- *Possibility of a broadly applicable model of nuclei;*

- *Synthesis of Superheavy elements.*

Nuclear Astrophysics:

- *The origin of heavy elements;*

- *Explosive nucleosynthesis;*

- *Composition of neutron star crusts.*
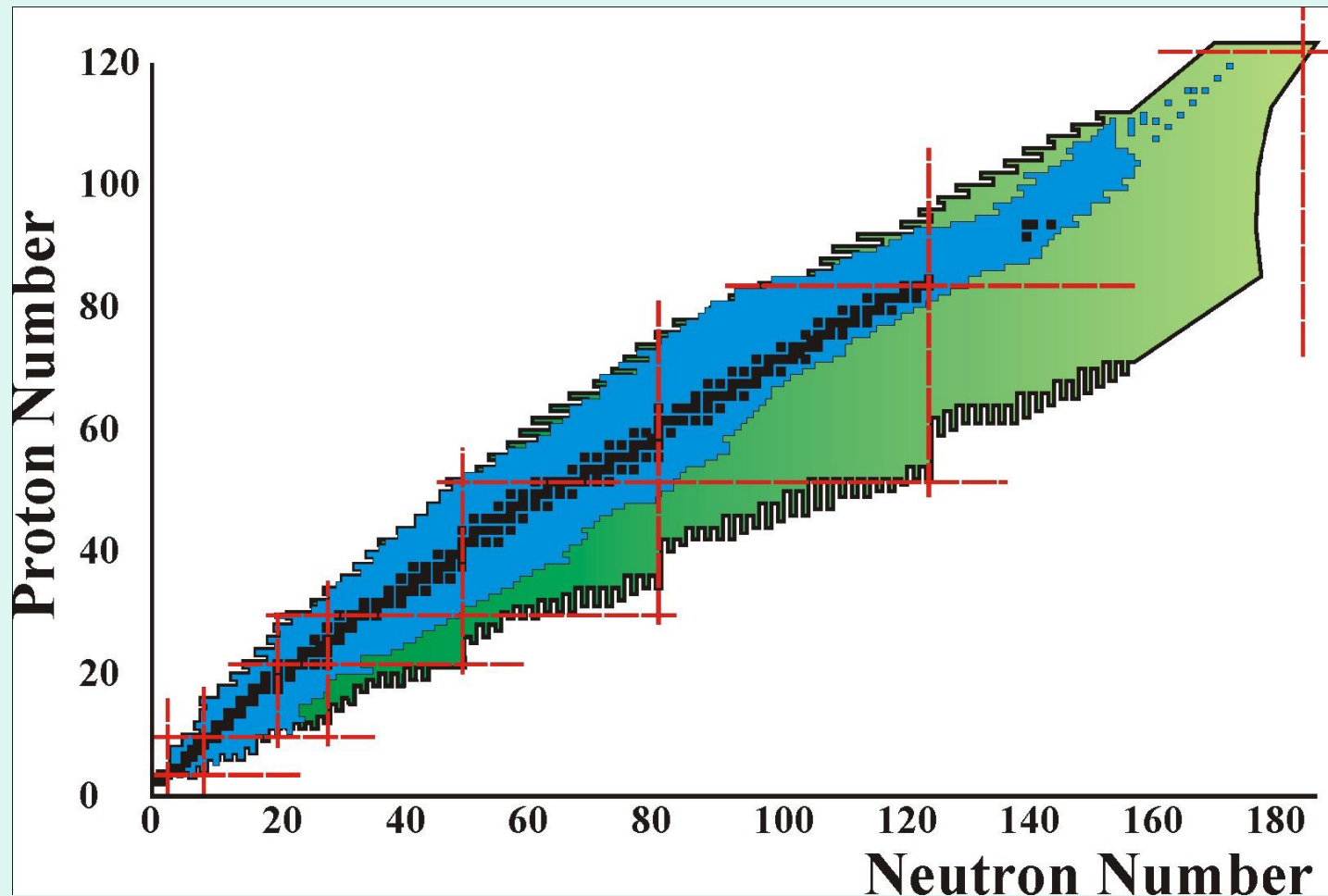
The black squares represent the stable nuclei. These nuclei form the valley of stability. The blue region indicates the shorter-lived nuclei produced in laboratory. The green region represents the incognita region up to the drip lines. Red vertical and horizontal lines show the magic numbers as known today near the stability valley.
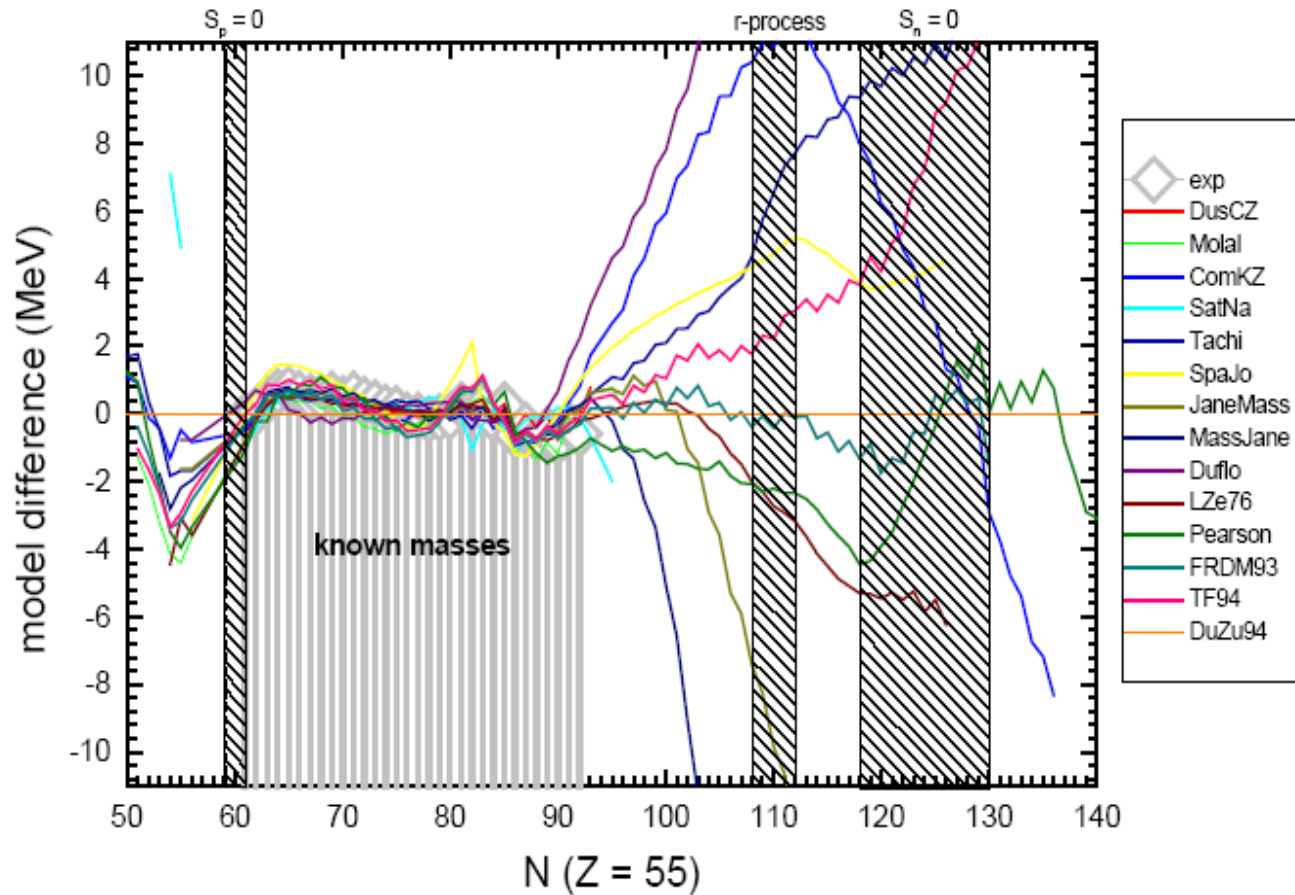
The difference between the masses (for the element Z = 55) calculated with different models, varying the neutron number. In the known masses region, the difference between the results of different models calculation is near to zero, but it diverges increasing the neutron number, approaching the region of interest for the astrophysical r-process and the neutron drip line.

Light drip line nuclei
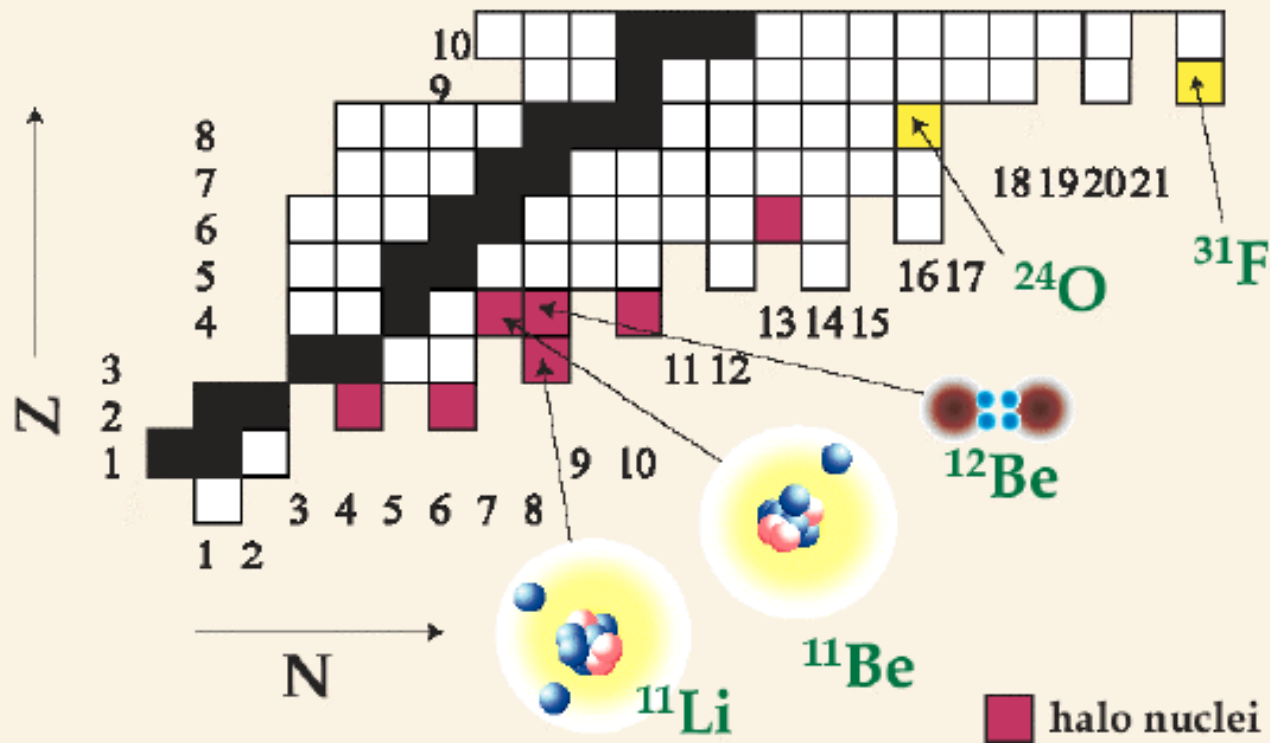
The neutron drip line has been explored only up to oxygen (Z = 8), where the heaviest particle stable isotope has 16 neutrons. The heaviest known isotope of fluorine (Z = 9) has 22 neutrons. Therefore one additional proton binds at least six neutrons. Purple squares indicate the known halo nuclei and a very elongated "dimer" configuration has been found for ¹²Be.

Experiments with exotic nuclei suggest some limitation to the single particle motion model. For example, near the neutron drip line, the binding energy decreases and the neutrons occupy orbits with a large spatial extension, creating a diffuse surface region. In this situation, the spin orbit force may be weakened, the pairing interaction and the presence of skin excitation can invalidate the picture of nucleons moving in single particle orbits.

In light nuclei, neutron halos with radii several times larger than those of stable nuclei with the same mass were observed. Halo neutrons move almost freely and their interaction is close to the bare interaction. Moreover the halo can give rise to collective excitation (the oscillation of the halo with respect to the core).

In heavy neutron rich nuclei the large N/Z ratio produces an excess of neutrons at large distance that gives rise to the important phenomenon of the neutron skin. To study the neutron skin effects, some isotopic chains with a fairly large difference in N/Z ratio

could be investigated.

The proton drip-line for even Z nuclei was explored up to Nikel (Z = 28), and partial information is also available around the magic numbers Z = 50 and Z = 82. The most interesting nuclei in the proton-rich region are those with N = Z and 60 < A < 100, where protons and neutrons occupy the same orbits and can give rise to a super-conducting phase carried by neutron-proton Cooper pairs.

At the heavy mass side of the nuclide chart the valley of stability ends and decay via cluster emission (alpha particles or fission) dominates over β-decay. The time-scale of α-decay mainly depends on the available decay energy (Q_α-value) compared to the height of the Coulomb barrier, but it can also be affected by some structure effects that can change the half-life of one or two orders of magnitude.

It is possible to identify in the nuclide chart some regions where the α-decay is the main decay process. To calculate the half-life for spontaneous fission processes is much more complicated due to the sensitivity on the height and on the shape of the fission barrier. Shell effects can stabilize the super-heavy elements over fission and the existence of limits in the super–heavy corner of the nuclide chart is still an open question.

In particular the proton and neutron magic numbers over the doubly magic ^{208}Pb are a matter of considerable debate. Non-relativistic models predict N = 184 and Z =124-126, where as relativistic theory favors N = 172 and Z = 120. Only by measuring the masses of super-heavy nuclei the puzzle will be solved and it will be possible to determine the shape of the spin orbit interaction in the super heavy region.
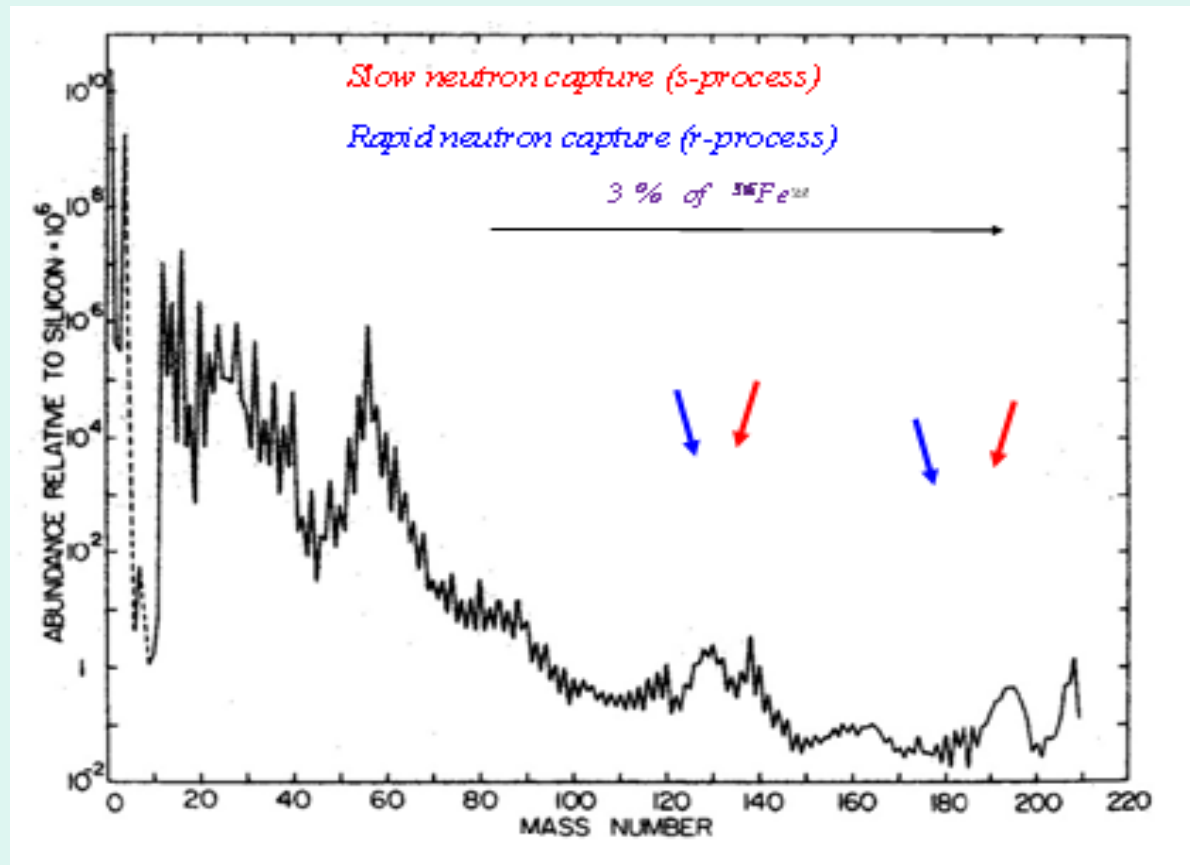
The solar system abundance of elements as function of the mass number. Two neutron capture process are responsible for the synthesis of elements heavier than iron. The slow neutron-capture accounts for the peaks indicated by the red arrows, whereas the rapid neutron-capture accounts for the peaks indicated by the blue arrows.
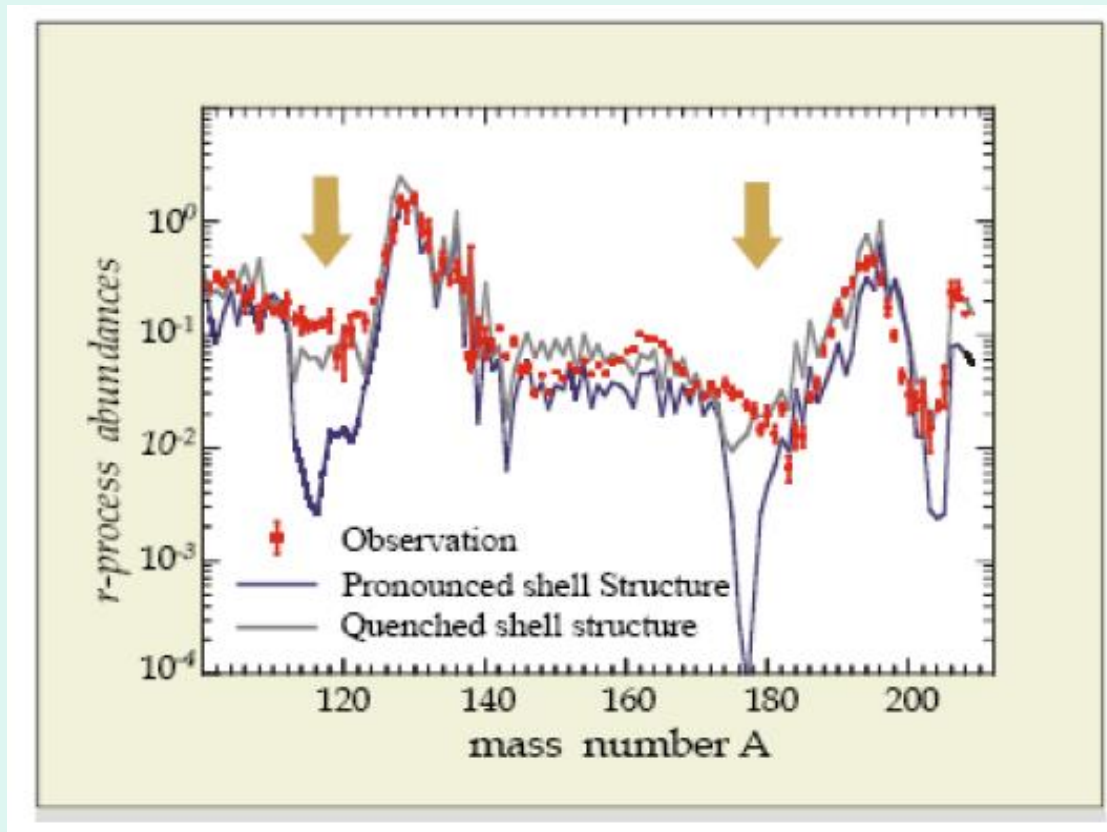
Experimentally determined r-process abundance (red dots with error bars), compared with two calculations that differ for the strength of the spin-orbit interaction. Spin-orbit quenching gives a better agreement with the data.

Nuclear properties of

THOUSAND nuclei located

near the neutron drip line

have to be measured.

Exotic nuclei are characterized by excess of neutrons or protons respect to the stability line, short half-life, neutron or proton dominated surface, low binding energy.

*The **ISOL** (Isotope Separation On Line) or the **IF** (In-Flight) technique. ISOL technique is currently used in many laboratories HRIBF (Oak Ridge), TISOL (Triumf), REX-Isolde (CERN), Spiral (GANIL), EXCYT (Catania).*
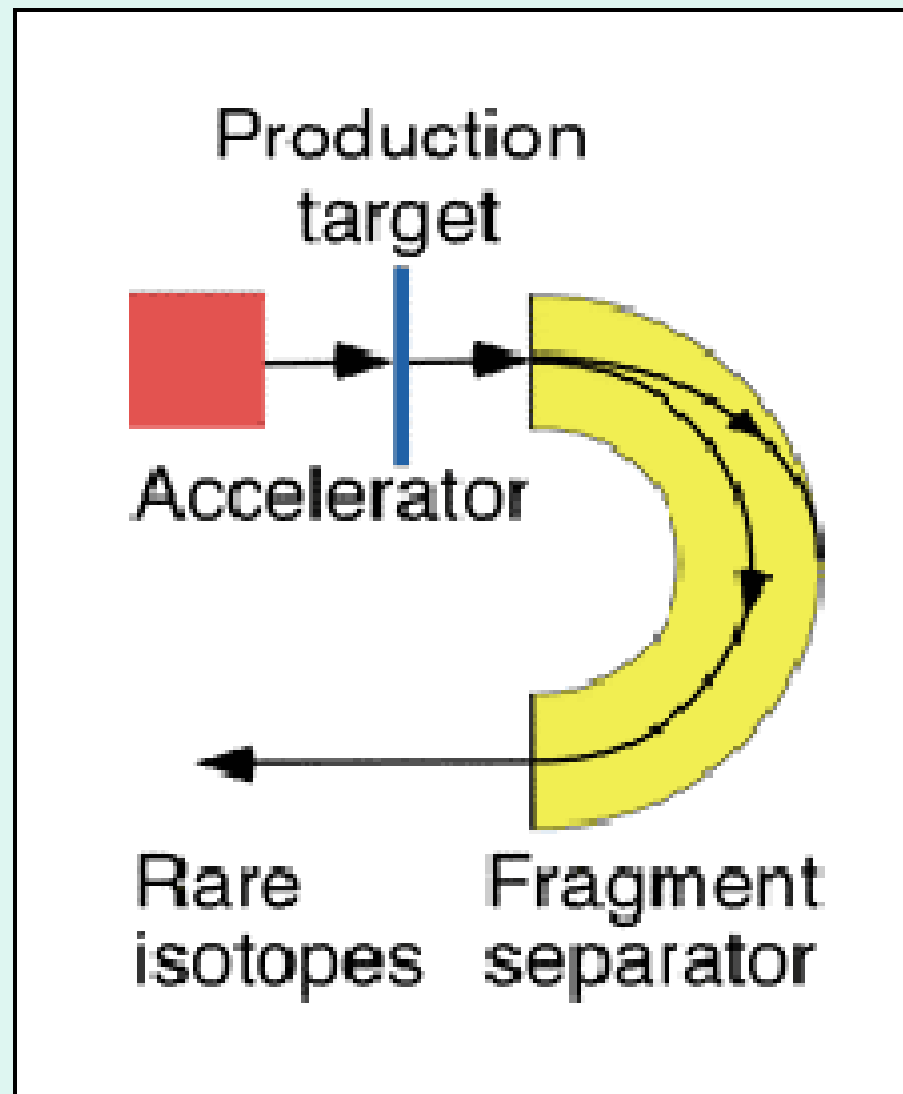
ISOL source:

light particles are used to bombard a thick heavy target producing the nuclear reaction products. The possible reactions are target fragmentation.
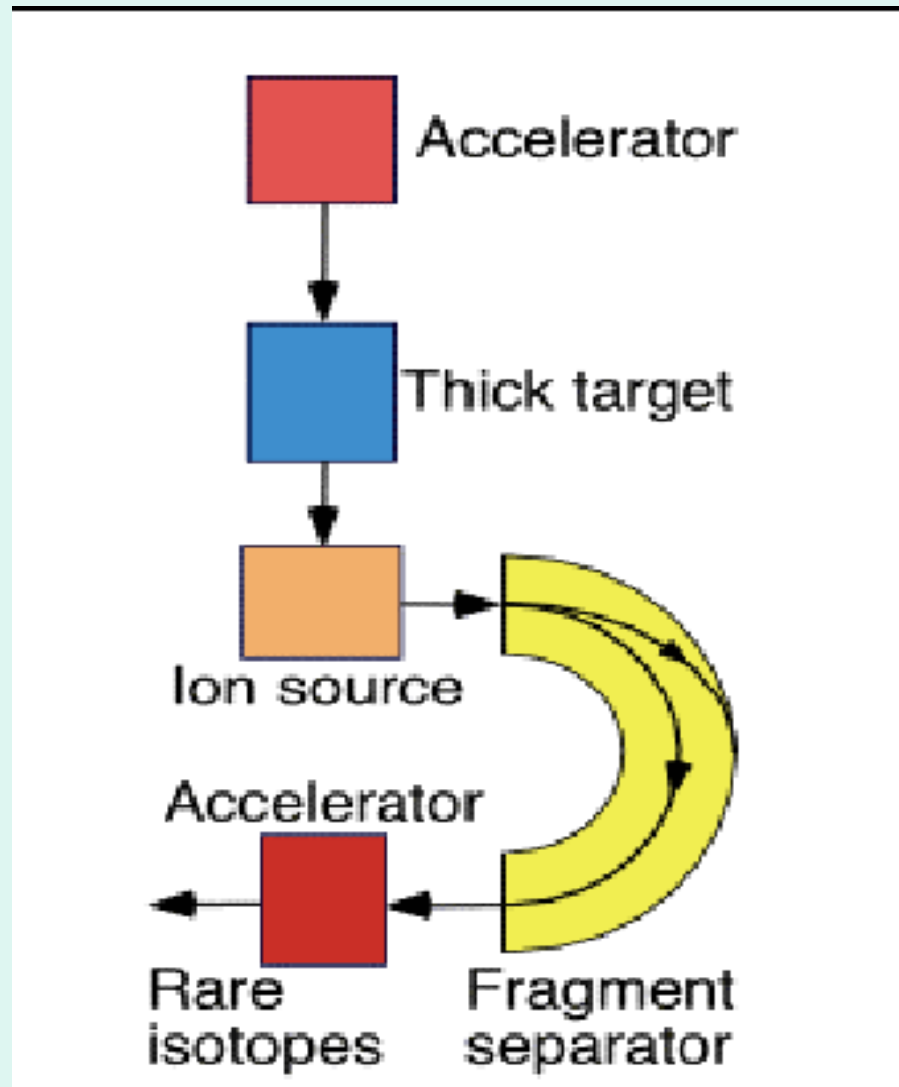
Schematic view of an ISOL facility

***IF technique** is used at GANIL (France), GSI (Germany), NSCL (USA), RIKEN (Japan). The IF involves target of light materials, heavy ion beam and produces the rare isotopes of interest by projectile fragmentation or fission reactions.*

Schematic view of an IF facility.

Preliminary Layout of the
A.I.Alikhanyan
National Science Laboratory
Heavy Ion Synchrotron
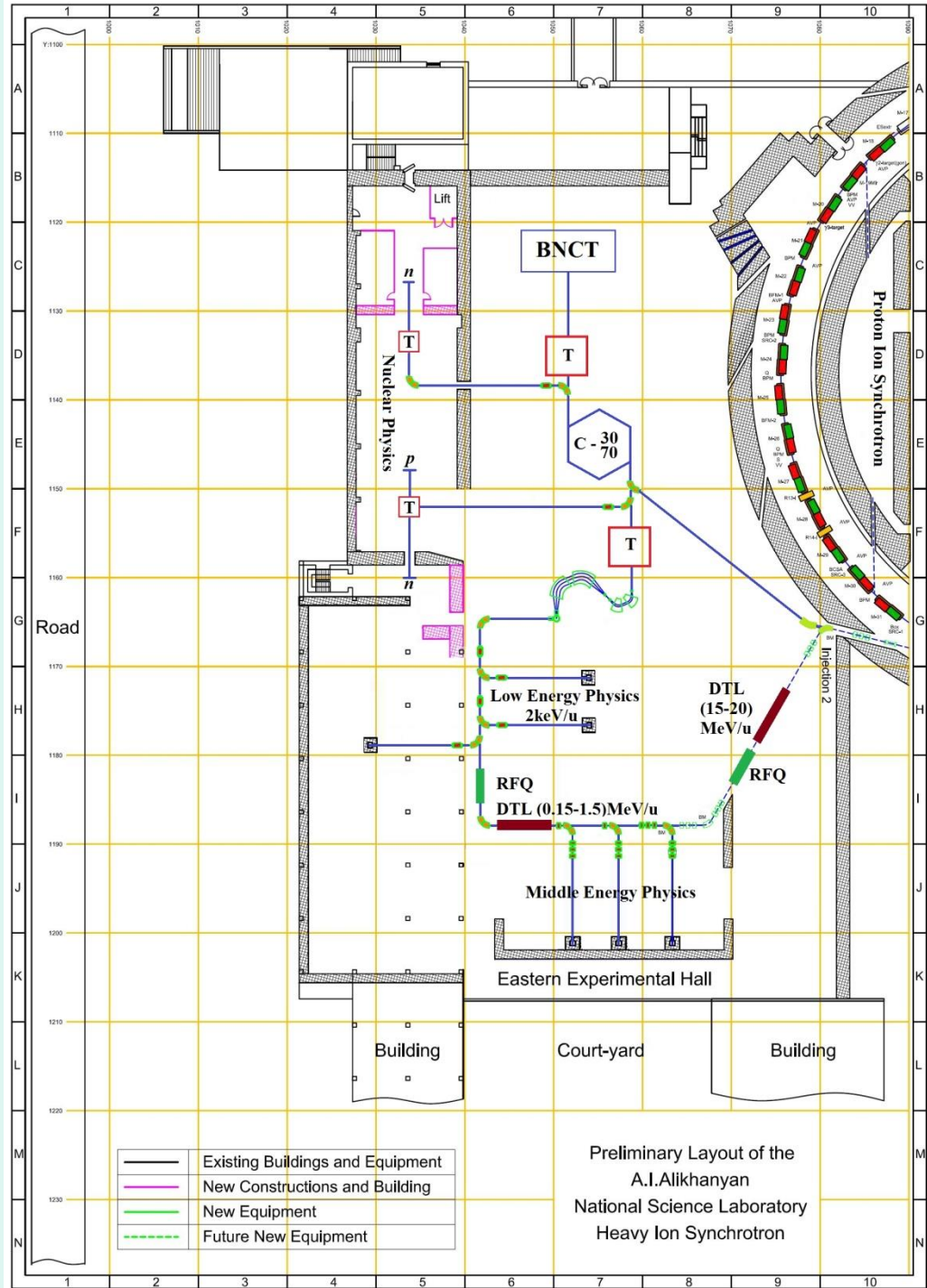
CYCLONE30

Cyclo-trons	Protons		Deuterons		Alpha	
	External beam energy, MeV	Beam current, μA	External beam energy, MeV	Beam current, μA	External beam energy, MeV	Beam current, μA
C30 LC	15-30	400	-			
C30 ST	15-30	800	-			
C30 HC	15-30	1500	-	-	-	-
C30 XP	15-30	400	8-15	50	30	50
C70	30-70	750	15-35	50	70	70

The nuclear physics program will include:

- *Investigations of nuclear excited states in proton-nucleus interactions;*

- *Investigations of heavy nuclei fission by 30-70 MeV high intensity protons;*

- *The isomeric pair production;*

- *The measurement of inelastic and elastic scattering differential cross sections;*

- *The measurement of the neutron captures cross section, a fundamental ingredient for the calculation of the stellar reaction rates and thus the possibility of reproducing the observed abundance of the elements in the Universe.*

Energy 30 MeV gives the possibility to produce radioisotopes:

As-74, Br-77, C-11, Cu-61, F-18, Ga-67, Ge-68, I-123, In-111, Kr-81m, N-13, O-15, Ta-179, Tc-99m, Tl-201, Xe-127, Zn-62   and

__BNCT__ is a cancer treatment in which cancer cells are killed by α particles and ^7Li nuclei produced through the $^{10}B(n,\alpha)^7Li$ reaction.

Both the α and the ^7Li produce closely spaced ionizations in the immediate vicinity of the reaction, with a range of approximately 5-9 μm or roughly the thickness of one cell diameter.
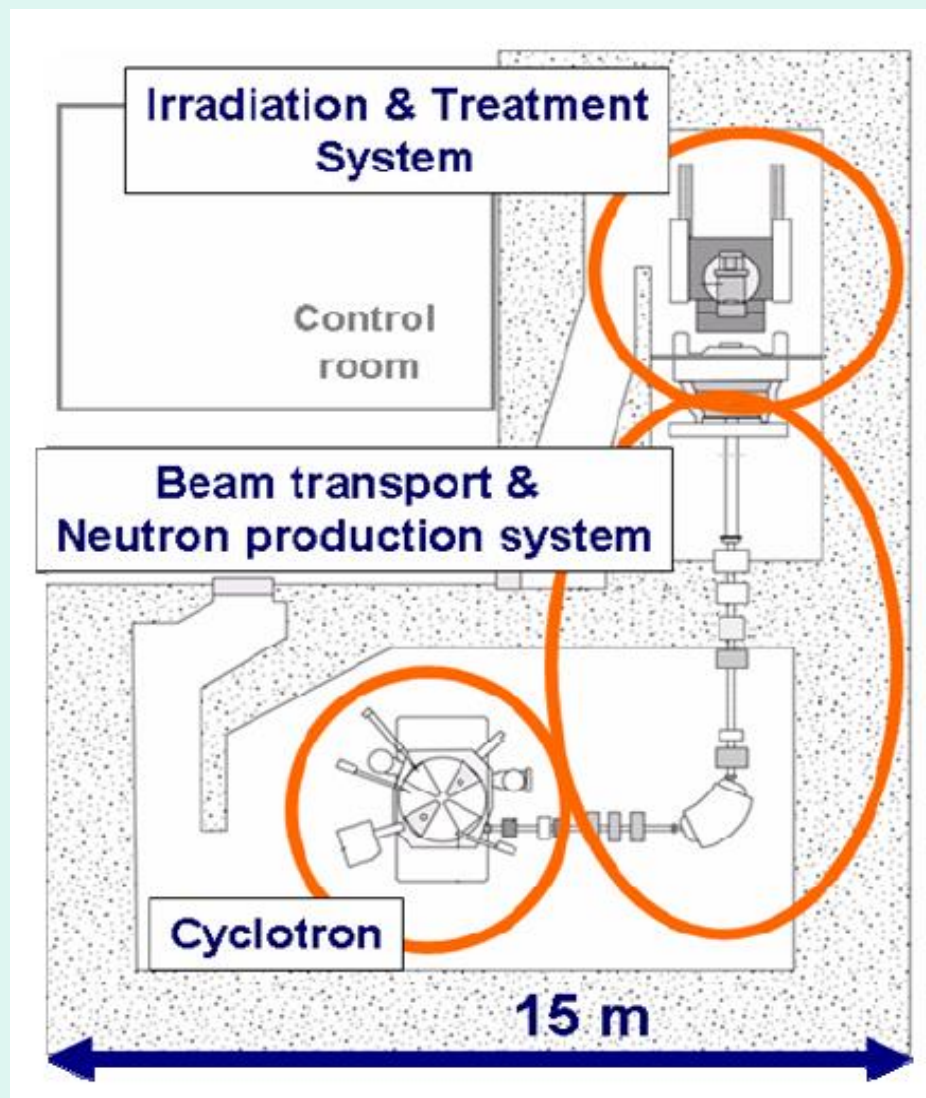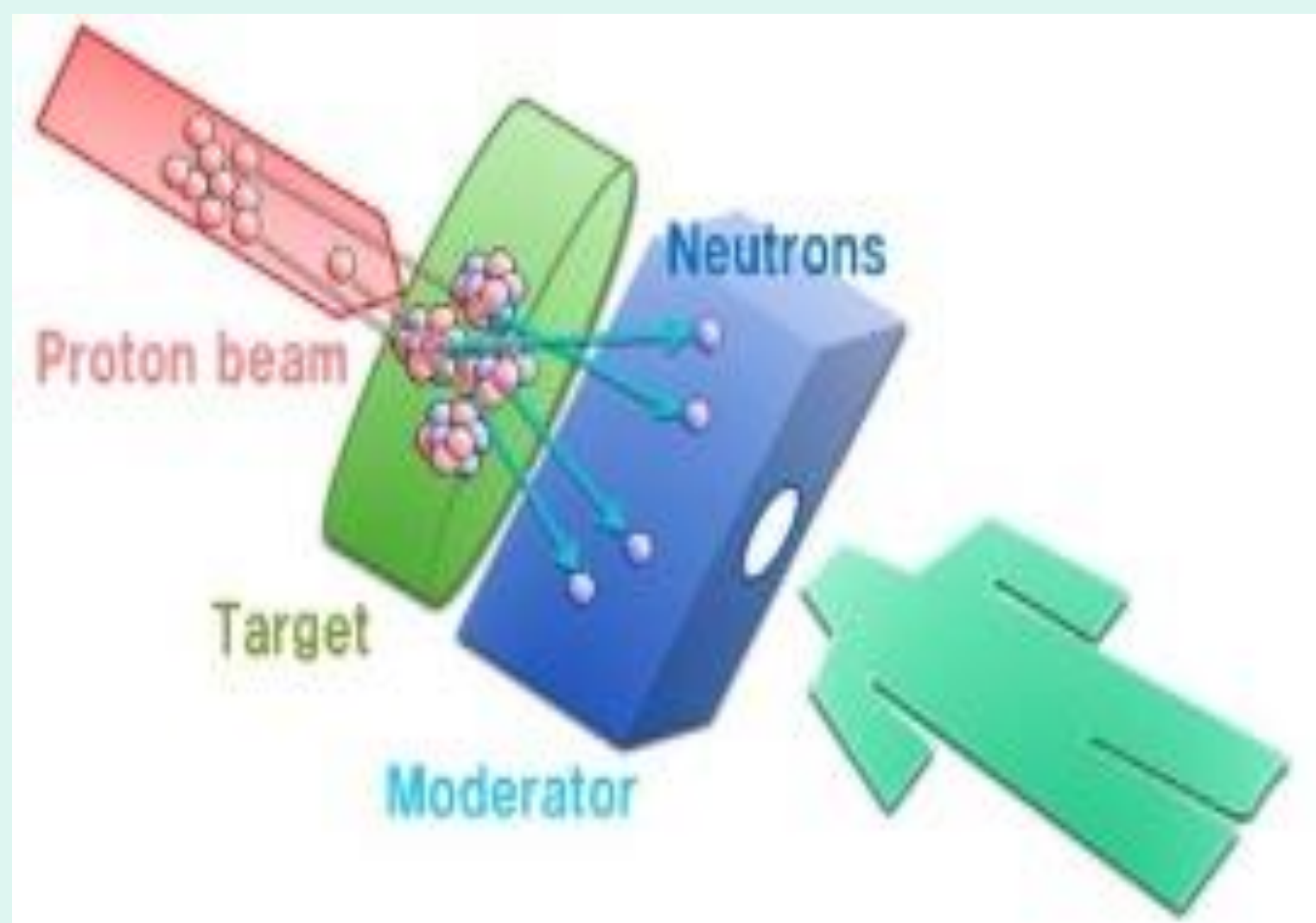
Irradiation & Treatment System

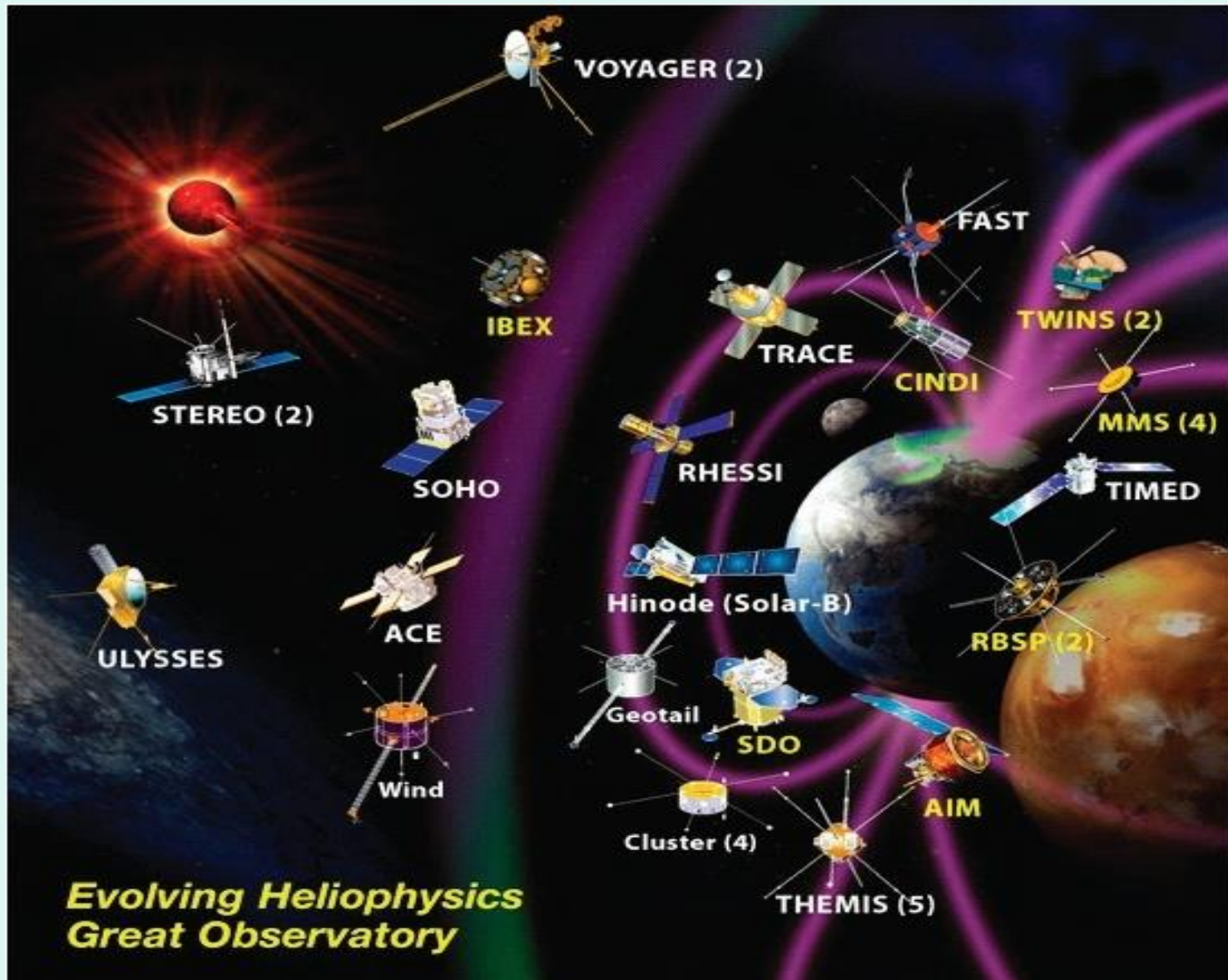Control room

Beam transport & Neutron production system

Cyclotron

15 m

Proton beam

Target

Neutrons

Moderator

The space environment is hostile

There are over 936 operating satellites in space, worth an estimated $200 billion to replace. They account for nearly $225 billion in revenue for the international telecommunications industry every year. These satellites are affected by events like cosmic rays, solar flares, energetic electrons.

Airline pilots and flight crews,

as well as frequent fliers,

receive increased doses of

radiation from solar flares.

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Thank you

for attention