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# Power Installations based on Activated Nuclear Reactions of Fission and Synthesis

**Abstract.** The general scheme of power installations based on nuclear reactions of fission and synthesis activated by external sources is analyzed. The external activation makes possible to support nuclear reactions at temperatures and pressures lower than needed for chain reactions, so simplifies considerably practical realization of power installations. The possibility of operation on undercritical masses allows making installations compact and safe at emergency situations. Installations are suitable for transmutation of radioactive nuclides, what solves the problem of utilization of nuclear waste products. It is proposed and considered schemes of power installations based on nuclear reactions of fission and fusion, activated by external sources, different from ADS systems. Variants of activation of nuclear reactions of fission (U-235, 238, Pu-239) and fusion (D, T, Li-6,7, B-10,11) are considered, designs of installations are proposed.

# Problems of Nuclear Power Engineering

## Atomic Power Stations

- Safety
  - Nuclear accidents: Chernobyl, Fukushima…
  - Nuclear terrorism
- Ecology
  - Radioactive fuel mining, enrichment…
  - Hundreds of tons of radioactive wastes
- Economy
  - High cost of nuclear power fuel and plants
  - Limited amount of fuel

## Thermonuclear Reactors

- Not realized
- Processing and Operating Complexity
  - Extra-high temperatures, pressures
- Economy
  - High cost of power plants

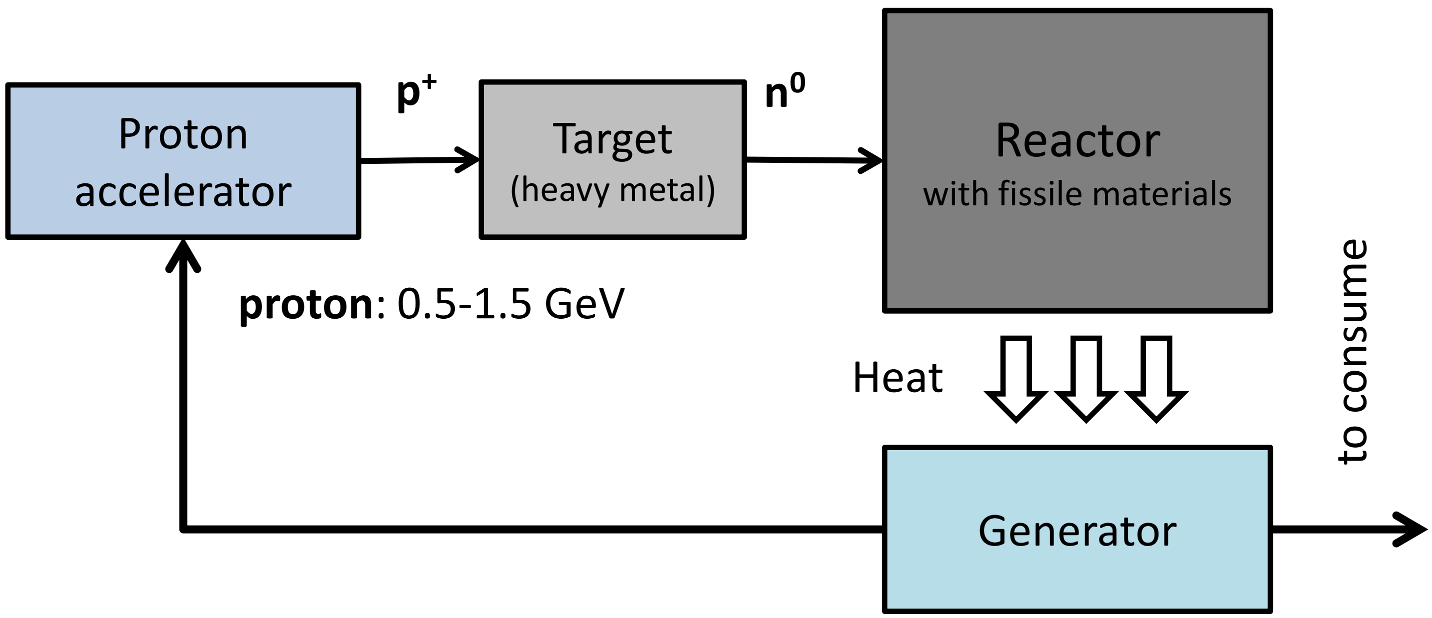
## Fast Neutron Reactors

- Safety
- Ecology
  - Radioactive fuel mining, enrichment
  - ~ Radioactive wastes
- Economy

## Accelerator-Driven Systems

- Processing and Operating Complexity
  - High-energy & intensity accelerator
- Ecology
  - Radioactive fuel mining, enrichment
- Economy
  - Low efficiency

# ADS Reactors



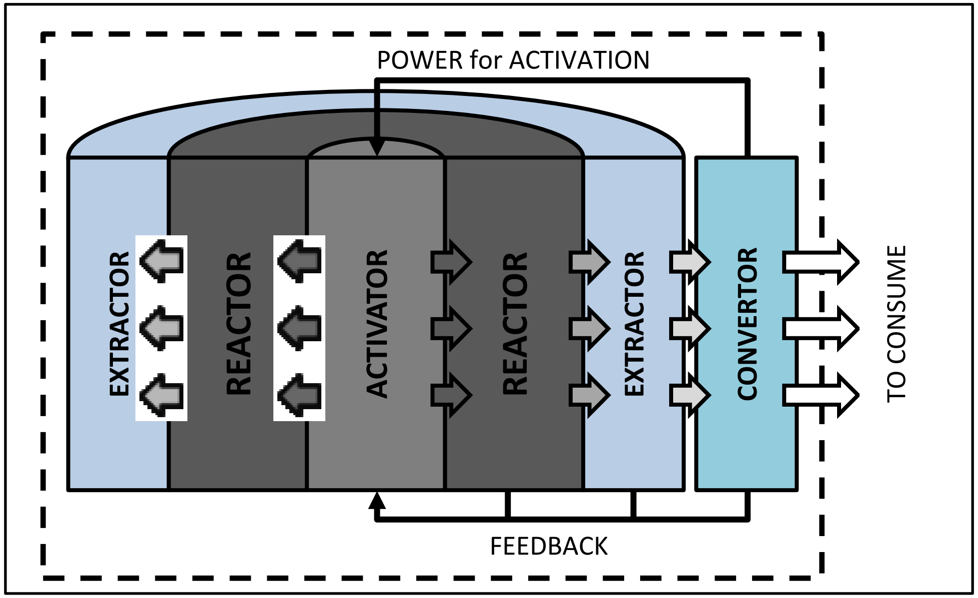

**Charged Particle Activation**

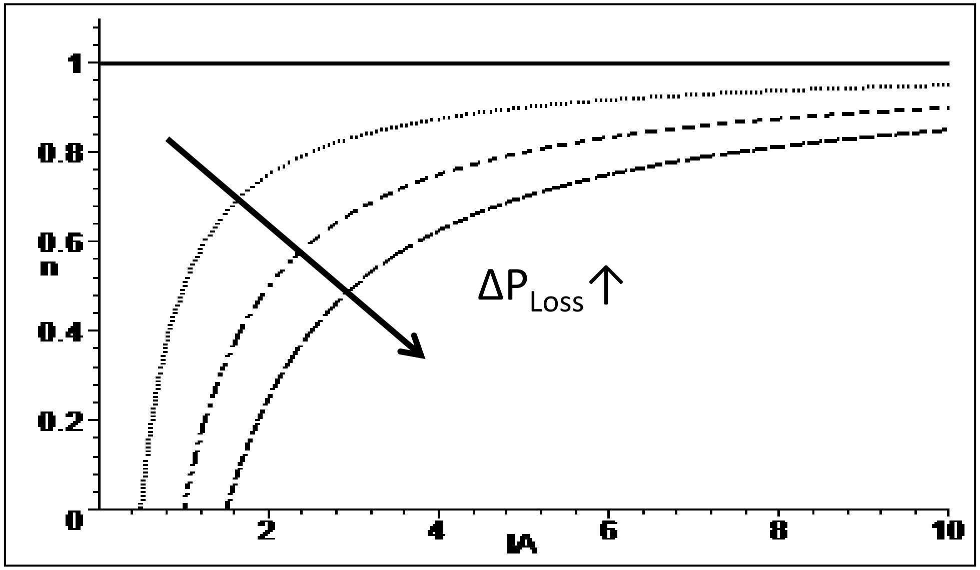
- Low σ of nuclear interactions
- Short length of neutron range (0.6 mm for Al)

**Neutron Activation**

\+ High σ of nuclear interactions
\- Acceleration?

# Efficiency of  NRA Installations




$$\eta = \frac{P_U}{P} \approx 1 - \frac{I_{th}}{I_A}$$

$$I_{th} = \frac{\Delta P_{Loss}(\eta = 0)}{\varepsilon_A k_L + \varepsilon_N k_N}$$

$$k_N = \frac{n_N}{n} \int_0^{E_A} \frac{\sigma_N(E)}{\sigma_{tot}(E)} dE$$

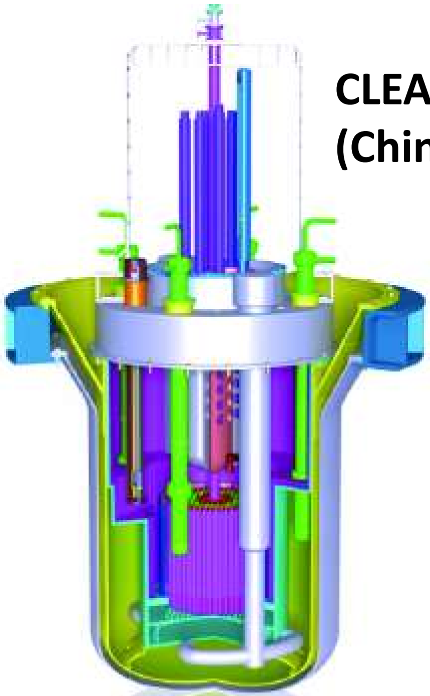
**ADS Reactors**

**proton**: 0.5-1.5 GeV

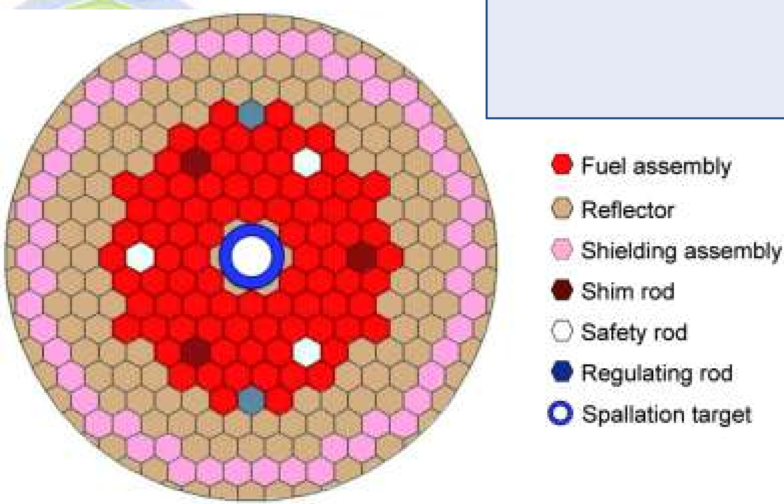
**Accelerator**: ~1.5MW

**Reactor**: 10 MW

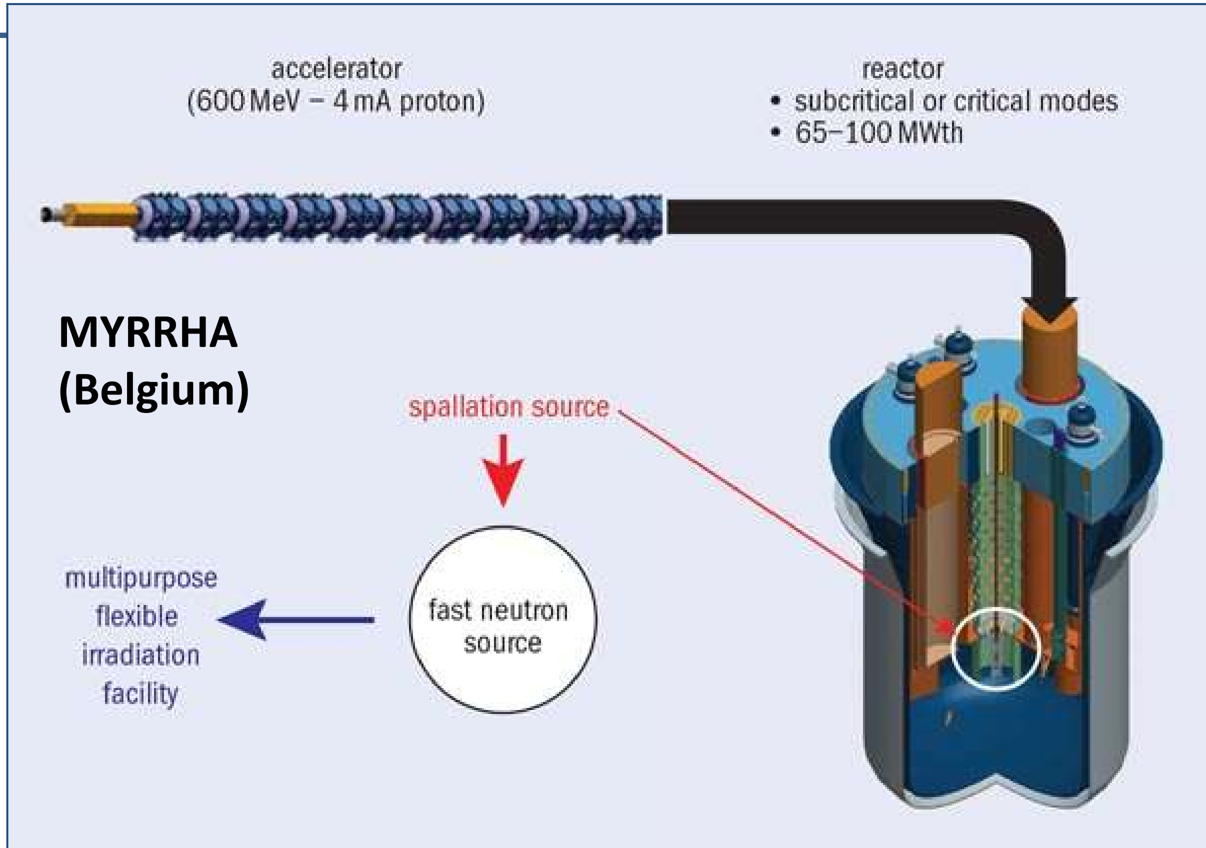
# ADS Reactors



**CLEAR-I (China)**




**MYRRHA (Belgium)**




**<u>ADS Reactors</u>**

**proton**: 0.5-1.5 GeV
**Accelerator**: ~1.5MW
**Reactor**: 10 MW

**Need for Activation:** $n^0$ ≤1 MeV **!**

# Neutron Activation

$$\left[\begin{array}{l} n + {}^{6}_{3}Li \rightarrow T + \alpha + 4.78\ \text{MeV}; \\ n + {}^{10}_{5}B \rightarrow {}^{7}_{3}Li + \alpha + 2.79\ \text{MeV}. \end{array}\right.$$

**Lithium-6**: 4.78/6=0.80 MeV/nucleon

**Boron-10**: 2.79/10=0.28 MeV/nucleon

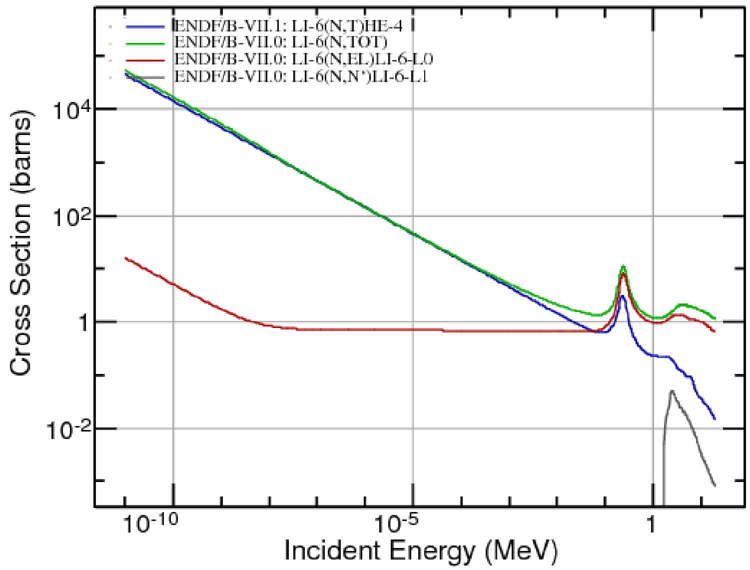
**Uranium-235**: 180/235=0.78 MeV/nucleon

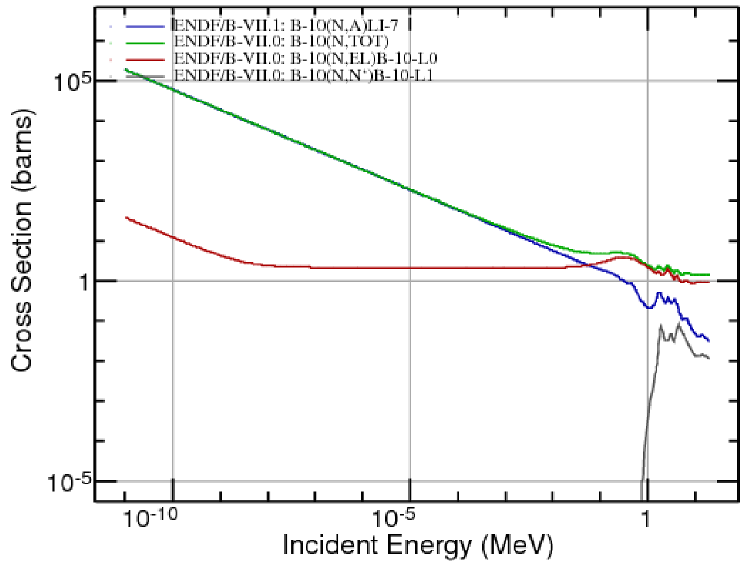
**Lithium-6**: 180/4.78=38 neutrons

**Boron-10**: 2.79/10=65 neutrons

**Uranium-235**: 180/180=1 neutron

**?**

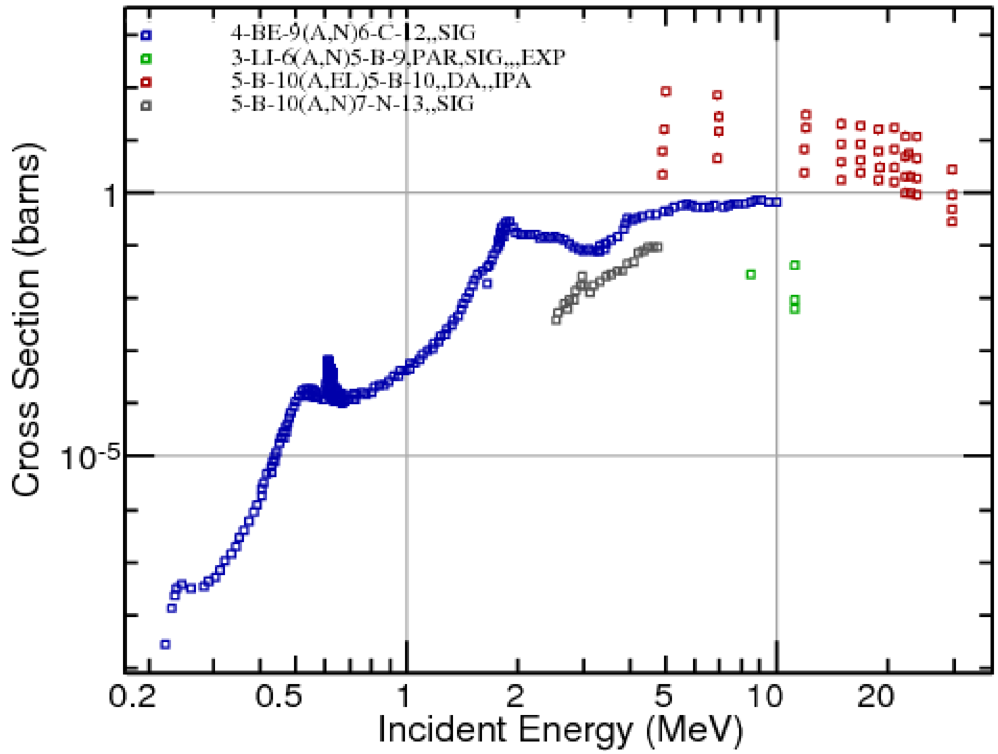


# Basic chain reactions

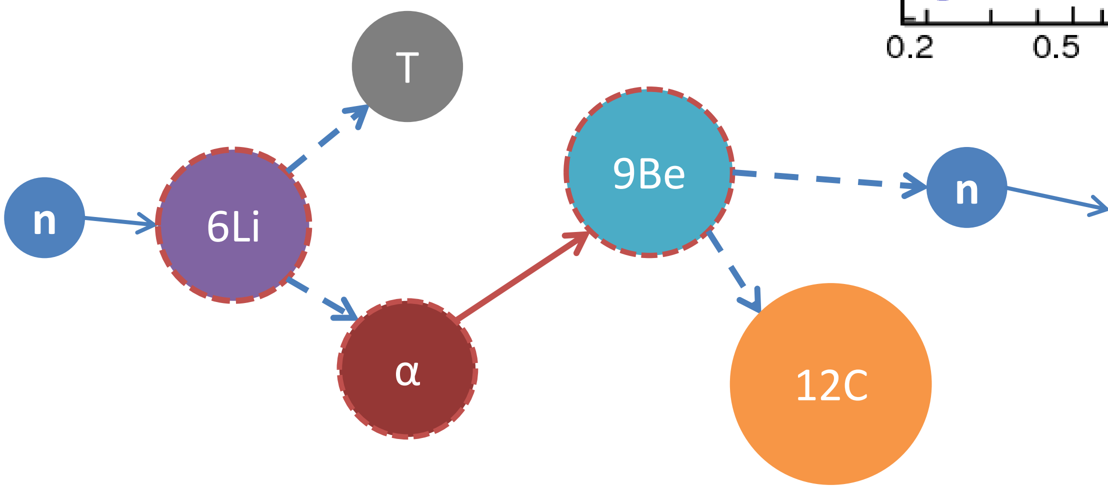
$$\left[\begin{array}{l} n + {}^{6}_{3}Li \rightarrow T + \alpha + 4.78\text{ MeV}; \\ n + {}^{10}_{5}B \rightarrow {}^{7}_{3}Li + \alpha + 2.79\text{ MeV}. \end{array}\right.$$

$$\alpha + {}^{9}_{4}Be \rightarrow n + {}^{12}_{6}C + 4.44\text{ MeV}$$




**Rival reactions:**

$^{6}Li(\alpha,n)^{9}B$ $\quad$ $^{10}B(\alpha,n)^{13}N$



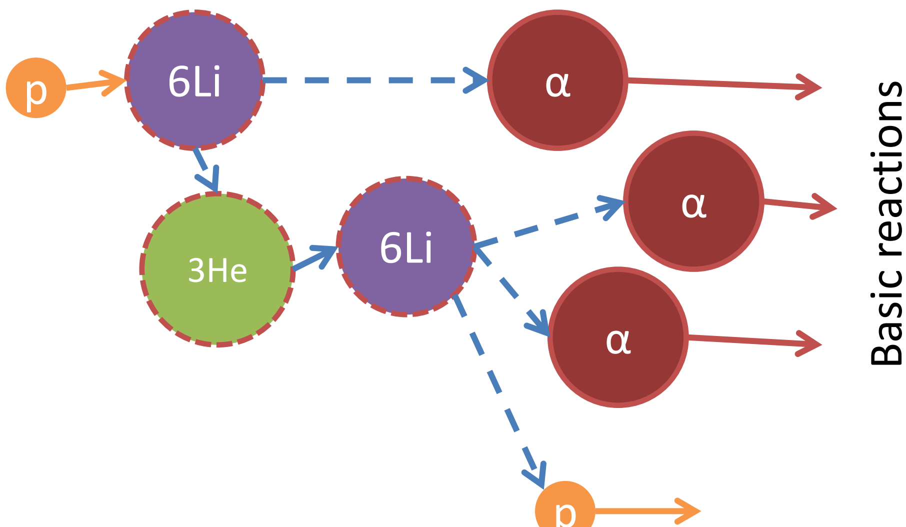

**Lithium-6**: 9.29 MeV

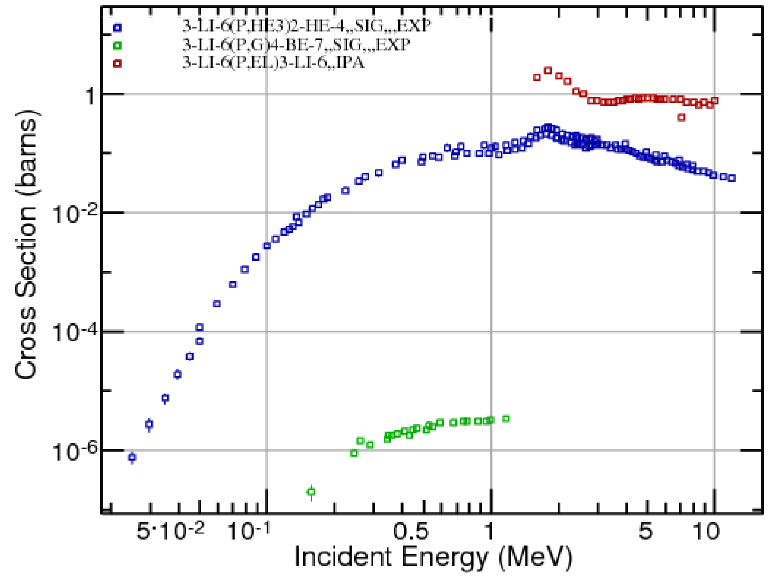
**Boron-10**: 7.23 MeV

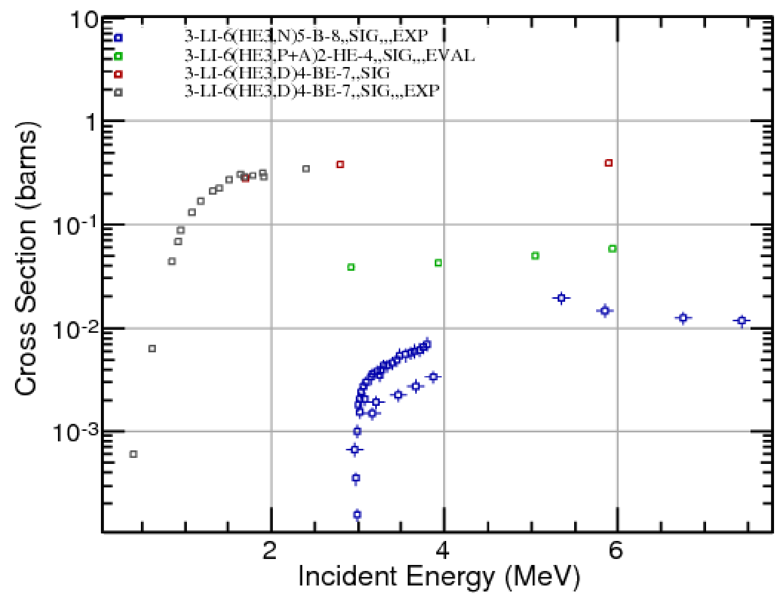
$K_n \approx 1$

# Proton – Lithium-6 Activation

$$\left[\begin{array}{l} p + {}^{6}_{3}Li \rightarrow {}^{3}_{2}He + \alpha + 4.0\ \mathrm{MeV}; \\ {}^{3}_{2}He + {}^{6}_{3}Li \rightarrow 2\alpha + p + 16.9\ \mathrm{MeV}. \end{array}\right.$$




**Rival reactions:**

$^{9}Be(p,2\alpha)D$ +0.56 MeV

$^{9}Be(p,\alpha)^{6}Li$ +2.1 MeV

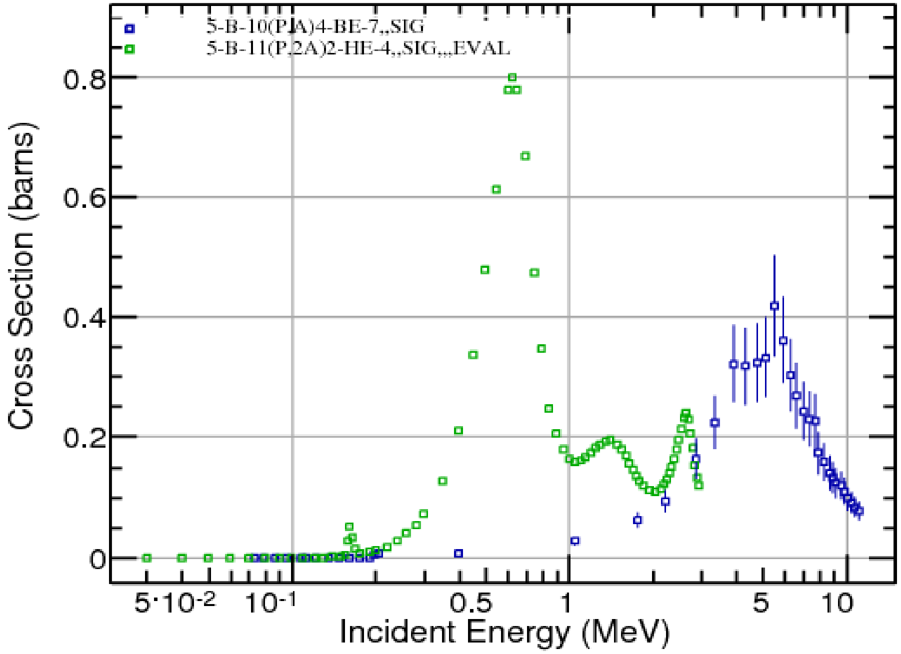
# Charged Particle Activation

**Lithium-6,7; Berillium-9:**

$$\left[\begin{array}{l} D + {}^{6}_{3}Li \rightarrow 2\alpha + 22.4\ \text{MeV}; \\ D + {}^{7}_{3}Li \rightarrow 2\alpha + n + 15.0\ \text{MeV}. \end{array}\right.$$

**Rival reactions:** ${}^{6}Li(D,n)^{7}Be$

${}^{6}Li(D,p)^{7}Li$



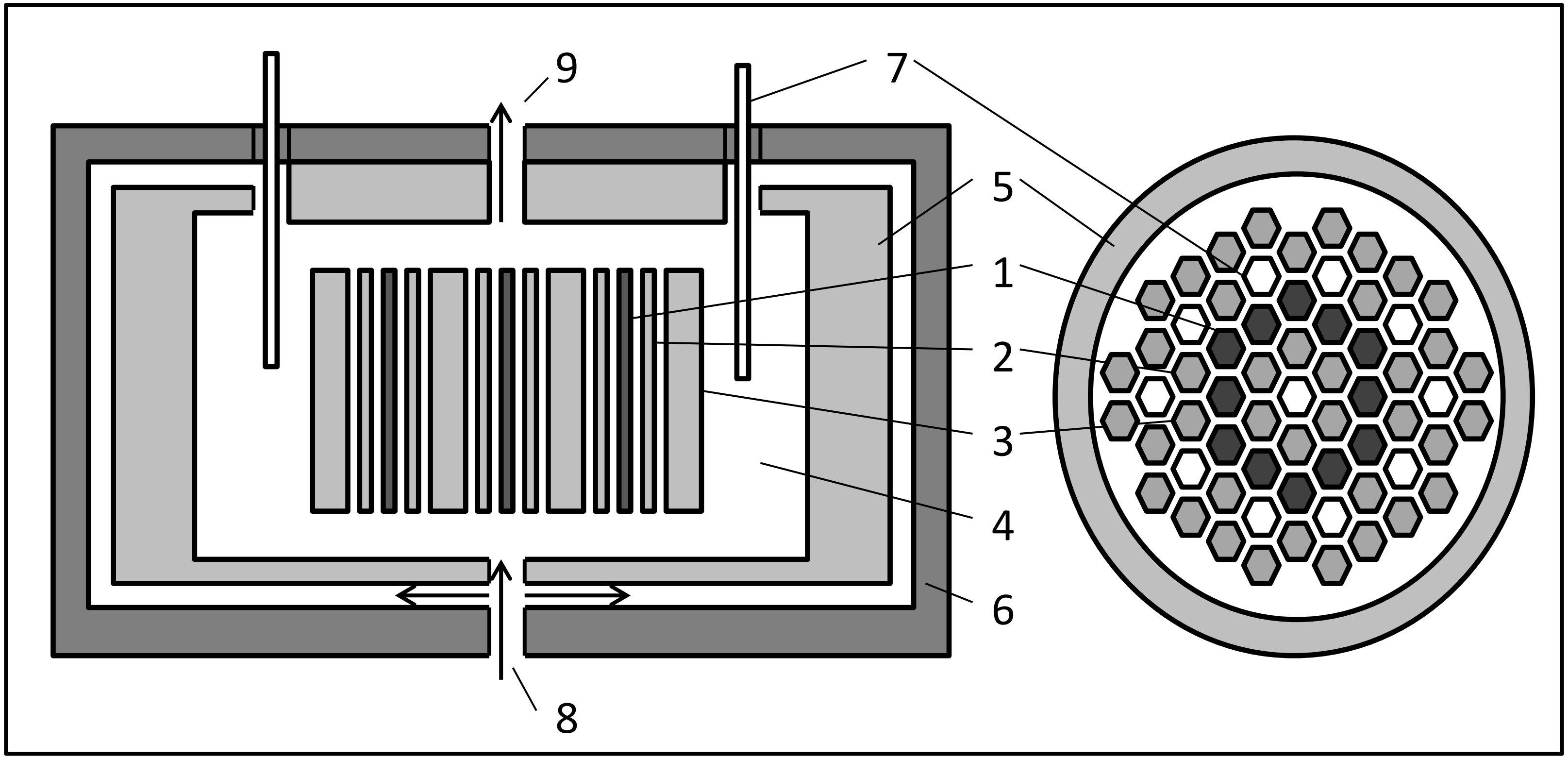

**Boron-10,11; Berillium-9:**

$$p + {}^{11}_{3}B \rightarrow 3\alpha + 8.7\ \text{MeV}$$

**Rival reactions:**

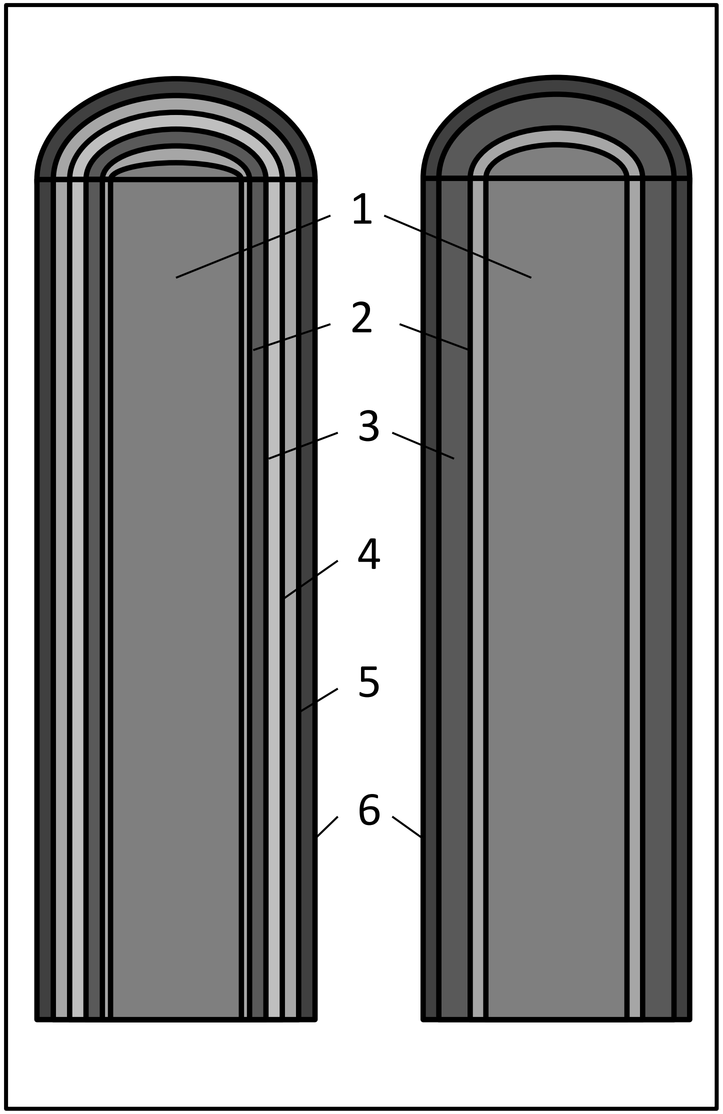
$${}^{10}B(p,\alpha)^{7}Be$$

# Nuclear-Thermonuclear Reactor




1 - activation pins with uranium or plutonium,
2 - basic pins with lithium-6 or boron-10 with beryllium-9 or without it,
3 – neutron moderators, 4 – the coolant, 5 – the neutron reflector,
6 – the reactor vessel, 7 – control rods,
8, 9 – coolant inlet and outlet.

# Autonomous Energy Sources




### Activating Neutron isotope sources

**Spontaneous fission**

$^{251}Cf$ ($T_{1/2}$=900 years), $^{249}Cf$ ($T_{1/2}$=351 years), $^{250}Cf$ ($T_{1/2}$=13,08 years), $^{252}Cf$ ($T_{1/2}$=2,645 years).

1 g of $^{252}Cf$ emits $3 \cdot 10^{12}$ neutrons per second

**Alpha-induced (α,n)**

$^{210}Po$, $^{226}Ra$, $^{239}Pu$, $^{241}Am$ (+ $^{9}Be$)

Usual neutron flux $10^{7}$-$10^{9}$ neutrons per second

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1 - lithium-6 or boron-10 with beryllium-9,
2 - neutron moderator,
3 - activating neutron isotope sources,
4,5 - neutron reflector and absorber,
6 - core vessel.

# Conclusion

The proposed power installations with activation of nuclear reactions are the nuclear-thermonuclear reactors and sources, in which fusion reactions are activated by fission ones. NTR installations do not need extra-high temperatures and pressures required for reactors on chain thermonuclear reactions and use much smaller amount of radioactive fuel than existing atomic power stations. It decreases considerably the amount of radioactive wastes in NTR and, for the most part, solves the ecological problems inherent to atomic power engineering. Decreasing an amount of radioactive materials with high neutron multiplication coefficient decreases the possibility of uncontrolled chain reactions, so it increases the operational safety of NTR power stations.

Nuclear-thermonuclear reactors can solve many serious problems of the nuclear and thermonuclear power engineering, but for practical realization of proposed installations a whole complex of researches, including theoretical and experimental investigations; detailed calculations; development of construction, etc., needs to be carried out.

# Thank You for Attention