Transmutation with fast neutrons

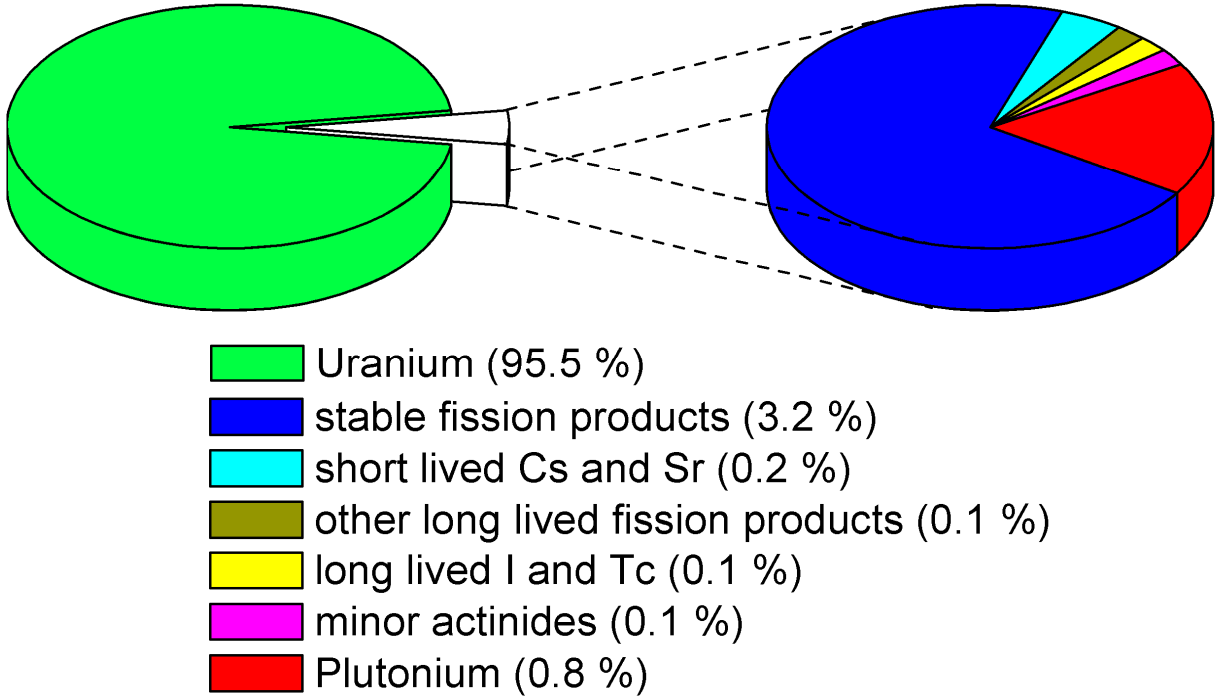
Experiments at nELBE

by Roland Beyer, Institute of Radiation Physics

Outline

- What is nuclear Transmutation?
- What are fast neutrons? What are they used for?
- What is nELBE? What can we do with it?

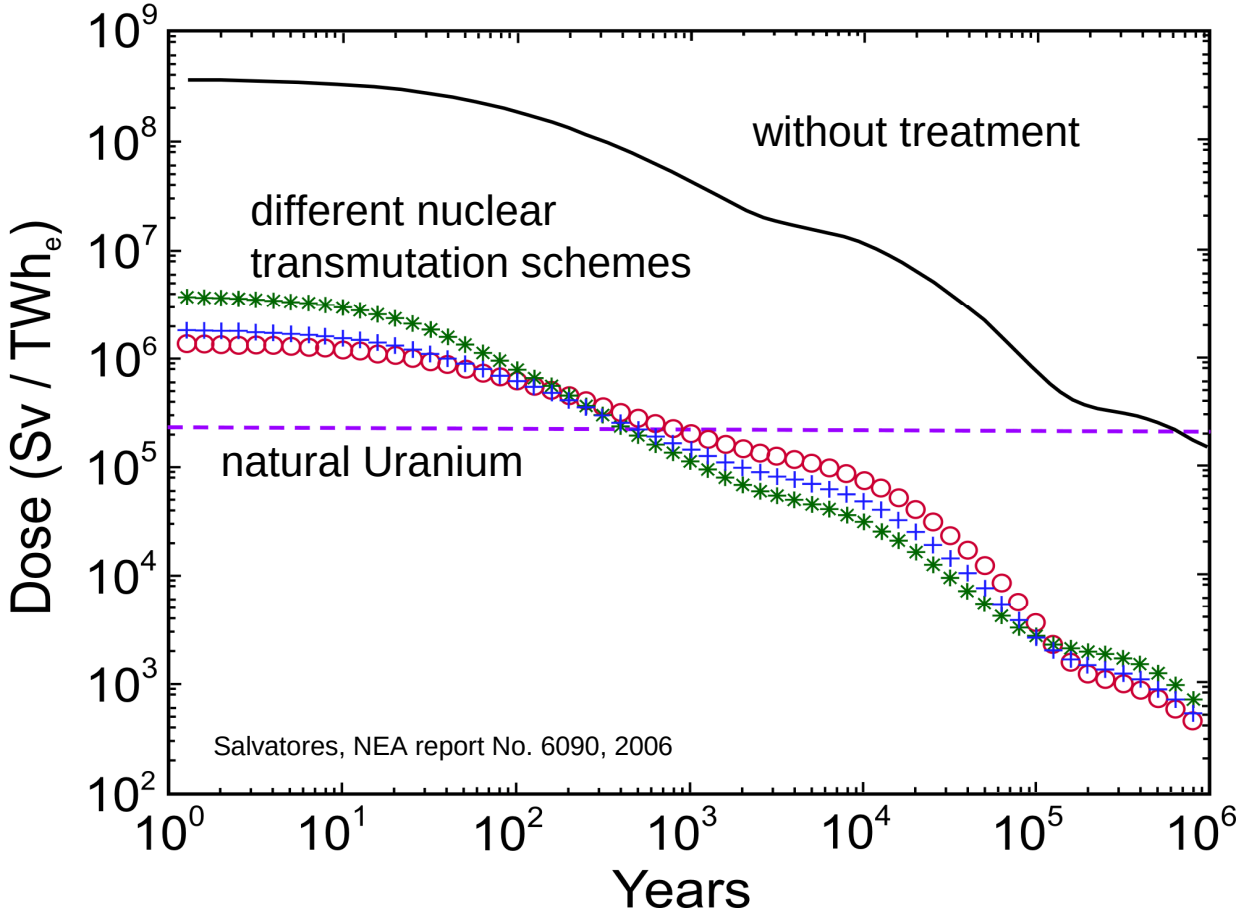
Composition of spent nuclear fuel



long lived isotopes cause main part of long term radiotoxicity

➔ **safe disposal is necessary for more 500 000 years**

Radiotoxicity of spent nuclear fuel

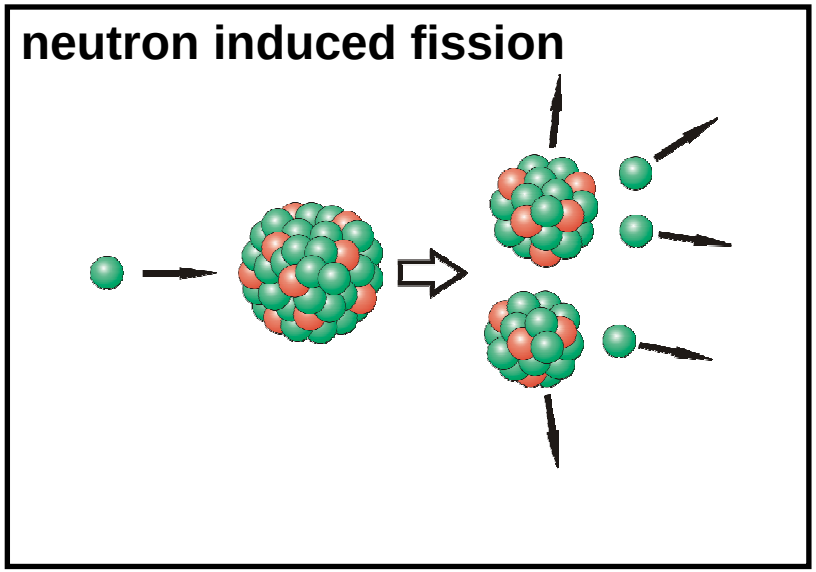


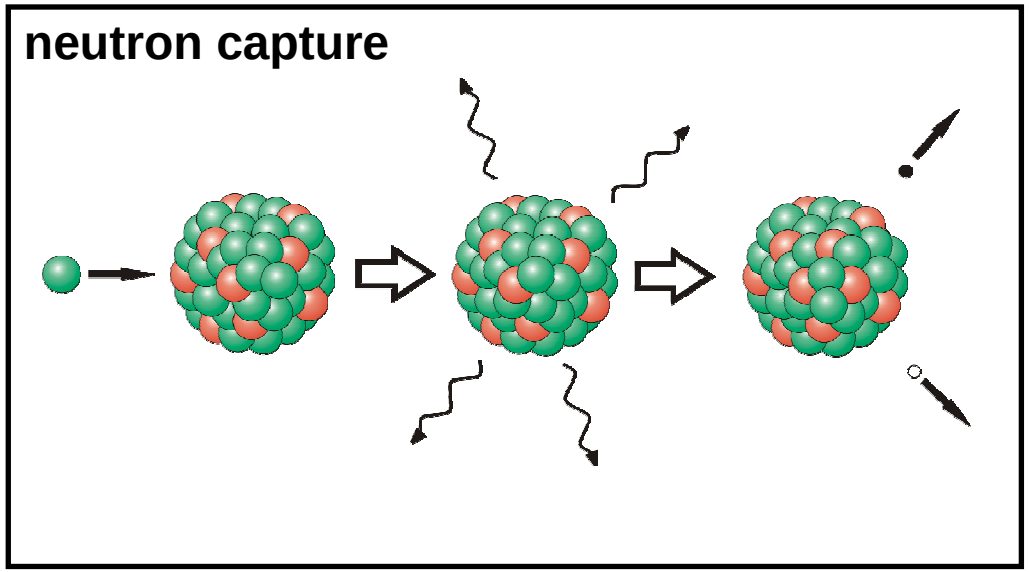
➔ treatment of nuclear waste can **reduce disposal time by 4 orders of magnitude**

➔ **Partitioning:** separate actinides from the rest

➔ **Transmutation:** convert long lived isotopes into short lived ones

Neutron induced reactions





$$^{1}_{0}n + ^{239}_{94}Pu \rightarrow ^{102}_{43}Tc + ^{135}_{51}Sb + 3\cdot ^{1}_{0}n$$

$$^{1}_{0}n + ^{129}_{53}I \rightarrow ^{130}_{53}I + \gamma \rightarrow ^{130}_{54}Xe + e^{-} + \bar{\upsilon}$$

$T_{1/2}$ = 2.4×10^{4} a 4.3 min 1.7 s 1.6×10^{7} a 12.4 h stable

neutron bombardment ➔ fission of heavy nuclei ➔ short lived fission products

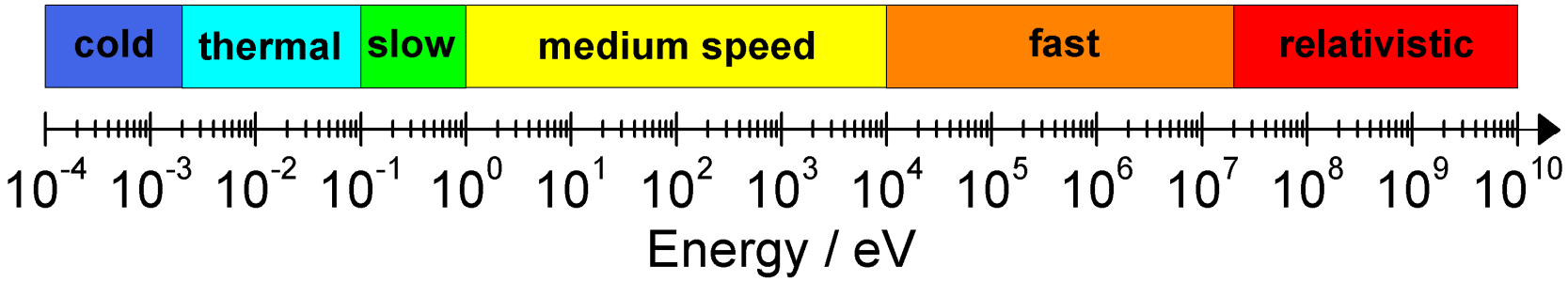
neutron bombardment ➔ neutron capture ➔ formation of short lived isotopes

Classification of neutrons?

The neutron: $^{1}_{0}n$

- Quark content: udd
- Mass: 1,67492721(9) x 10^{-27} kg
  = 1,0086649156(6) u
  = 939,56536(8) MeV/c^2
- Life time: 885,7(8) s

Classification:

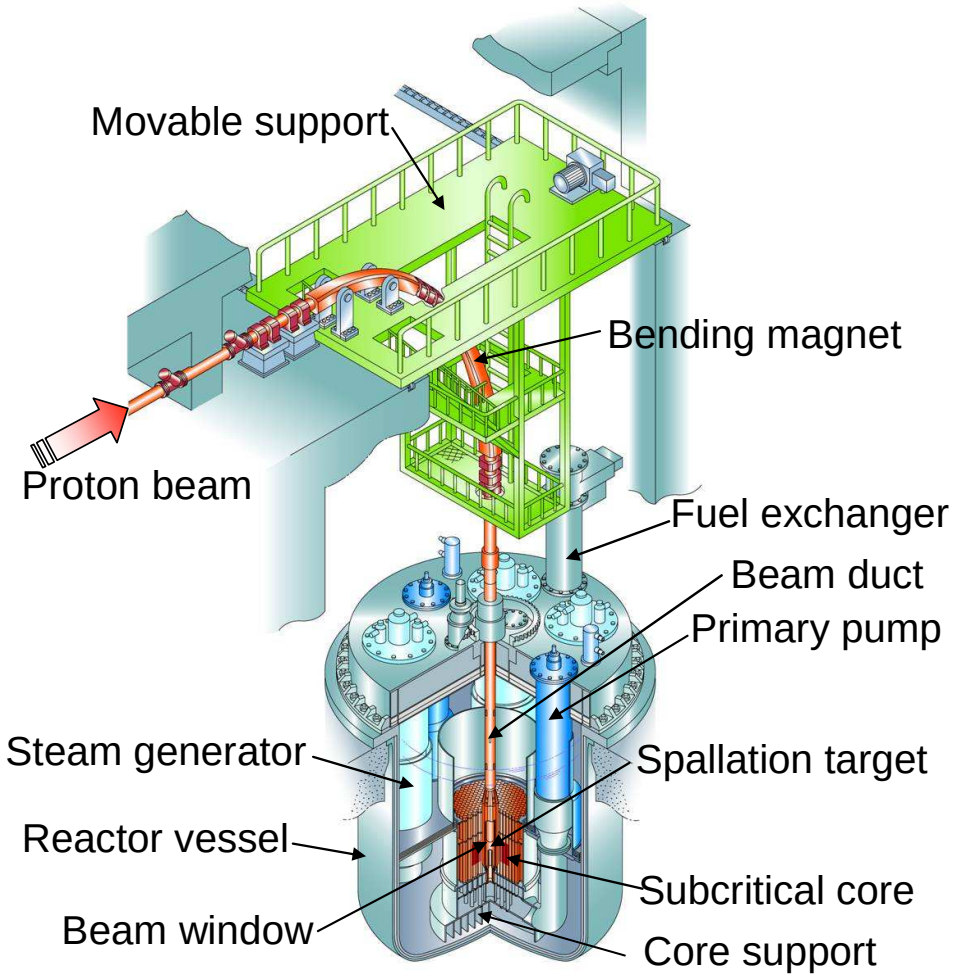


Accelerator driven Systems

- high energy protons (~1.0 GeV) are used to produce an intense neutron flux via **spallation** on heavy nuclei (e.g. Pb, Bi)

→ heavy nuclei will be smashed into some lighter ones and tens of fast neutrons

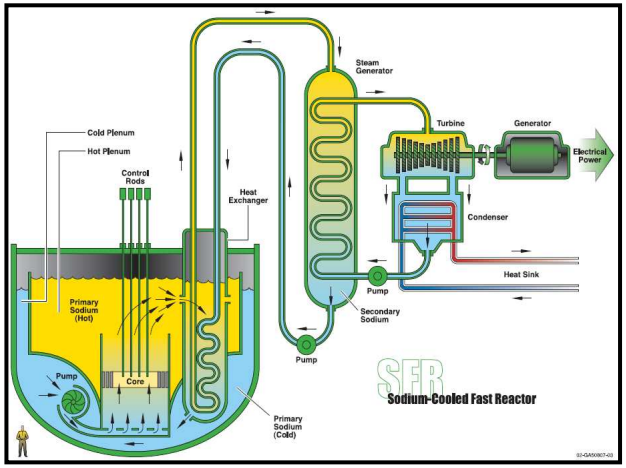
→ fuel will be composition of conventional fuel and nuclear waste



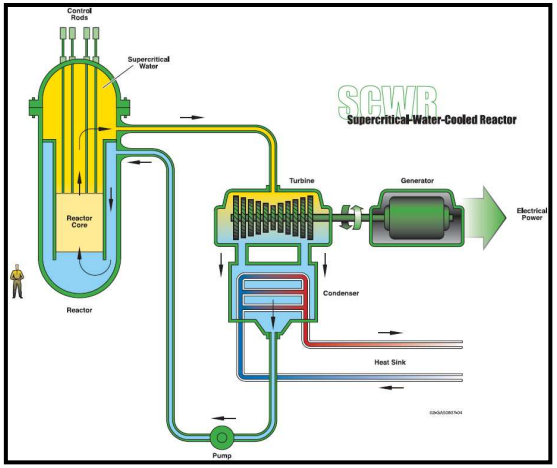
Hiroyuki OIGAWA, Presentation at Euratom PARTRA Cluster Meeting at FZK, Feb. 2008

Generation IV Nuclear Reactors

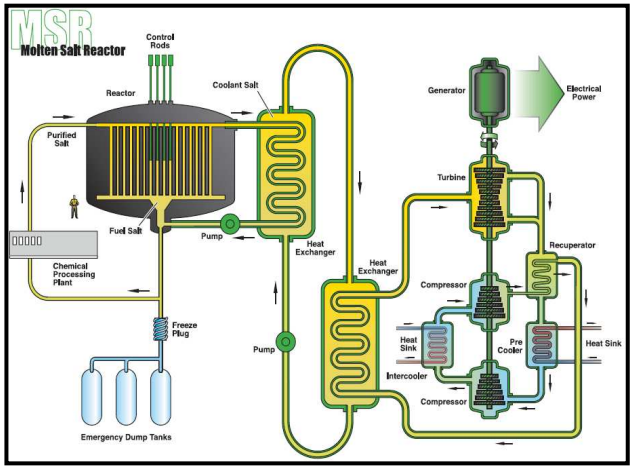
http://www.gen-4.org/Technology/roadmap.htm



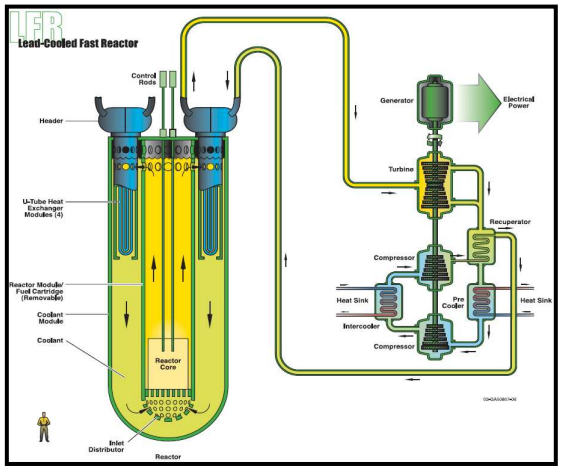
Sodium Fast Reactor



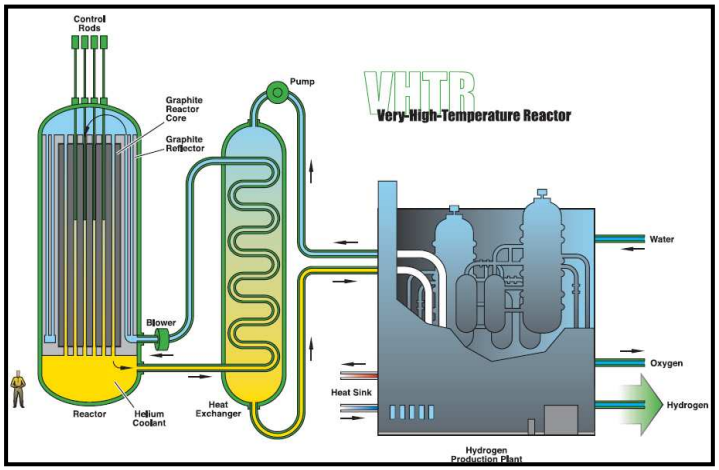
Supercritical Water Reactor



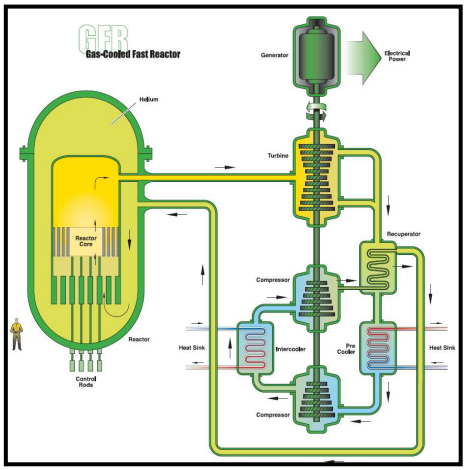
Molten Salt Reactor



Lead Fast Reactor



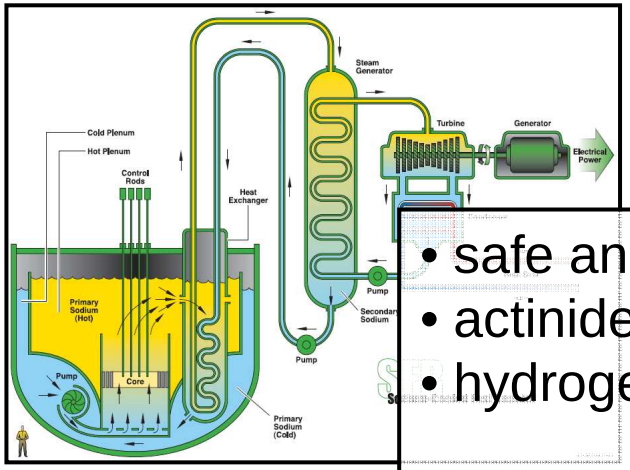
Very High Temperature Reactor



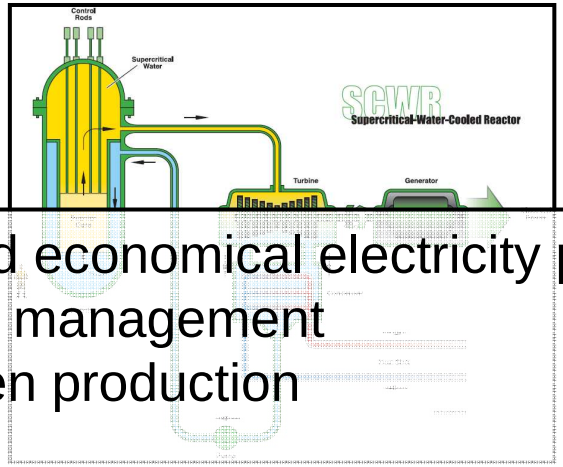
Gas Fast Reactor

Generation IV Nuclear Reactors

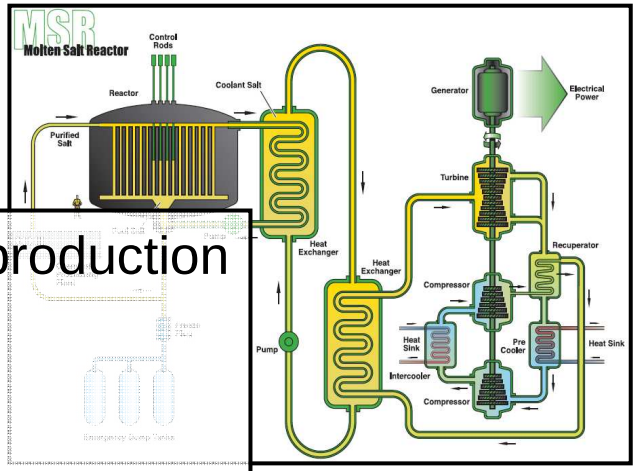
http://www.gen-4.org/Technology/roadmap.htm



Sodium Fast Reactor



Supercritical Water Reactor

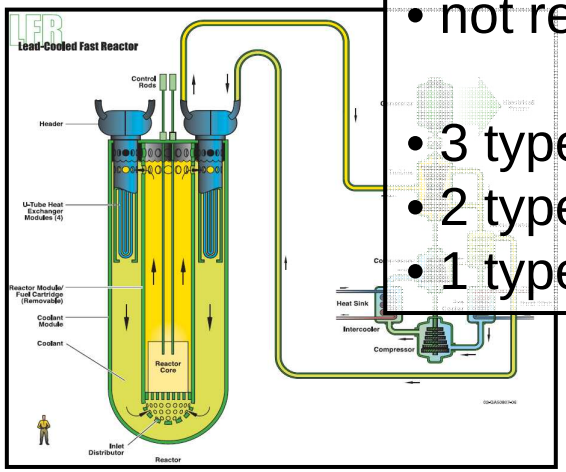


Molten Salt Reactor

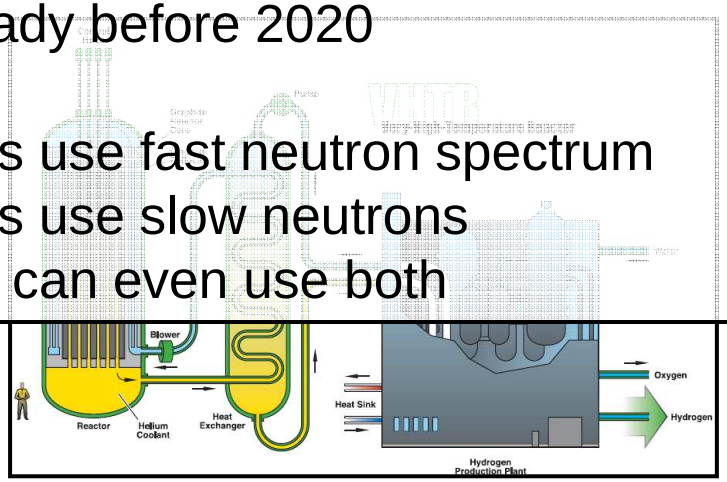
- safe and economical electricity production
- actinide management
- hydrogen production

- under development
- not ready before 2020

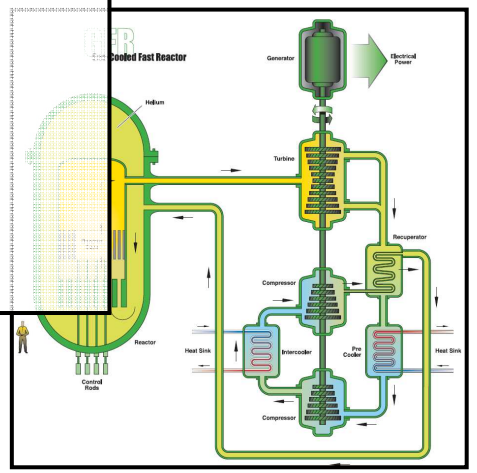
- 3 types use fast neutron spectrum
- 2 types use slow neutrons
- 1 type can even use both



Lead Fast Reactor



Very High Temperature Reactor



Gas Fast Reactor

Data Needs

- for simulations and calculations to design such facilities **detailed knowledge about the neutron interactions are necessary**

→ for nuclei to be transmuted as well as for structural materials

Object	Nuclides/Elements
Target materials	^{209}Bi, ^{208}Pb, ^{207}Pb, ^{206}Pb, ^{204}Pb Pb, ^{186}W, ^{184}W, ^{183}W, ^{182}W, W, ^{181}Ta, Ta, Zr, Sn, Hg, U, Pu, F, Cl, Na, Fe, Al
Po production	^{209}Bi(p,xn)$^{207, 208, 209}$Po, ^{209}Bi(n,γ)^{210}Bi--> ^{210}Po
Minor actinides	^{237}Np, ^{238}Np, ^{241}Am, ^{242m}Am, ^{242}Am, ^{243}Am, ^{242}Cm, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{248}Cm
Long-lived FP	^{79}Se, ^{93}Zr, ^{99}Tc, ^{107}Pd, ^{126}Sn, ^{129}I, ^{135}Cs
Fuel compositions	^{238}U, ^{235}U, ^{239}Pu, ^{238}Pu, $^{14, 15}$N, O, F, Cl
Th cycle	^{232}Th, ^{231}Pa, ^{232}Pa, ^{233}Pa, ^{233}U, ^{234}U
Structural materials	Zn, Cu, Ni, Co, Fe, Mn, Cr, Ti, Ca, Ar, Al, Mg, Na, O, N. C, B, Be, He ^{3}T
Shielding	O, Si, P, Ca, Ti, Fe

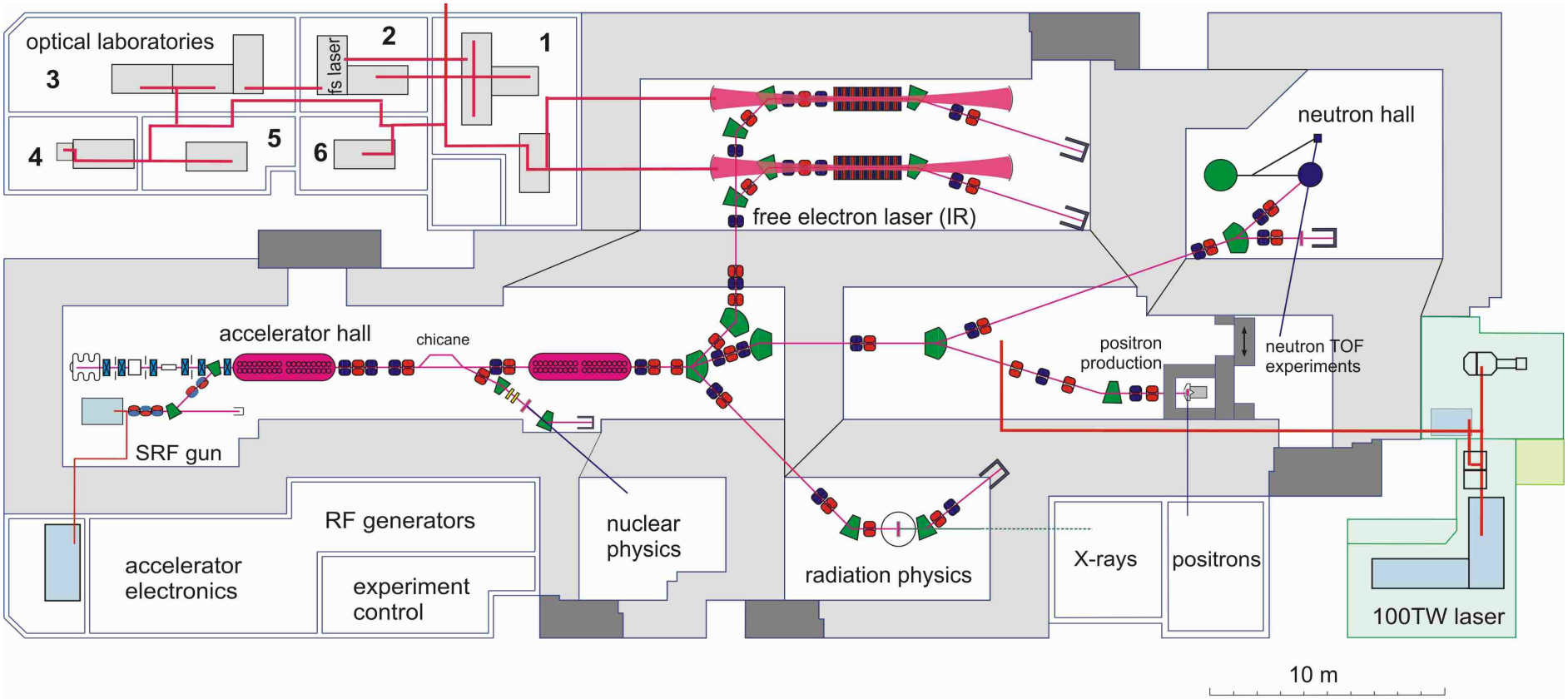
Y. Ikeda, Journal of Nucl. Sci. and Technology (2002) pp. 13-18

measure reaction cross section in dependency of neutron energy $\sigma(E_n)$

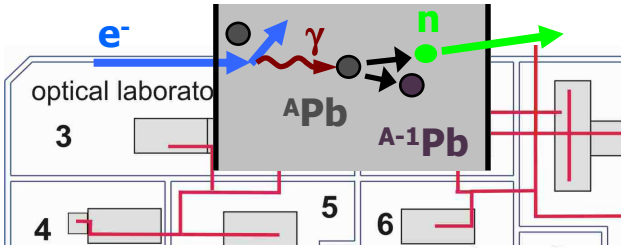
➔ ^{56}Fe (n,γ) ^{57}Fe

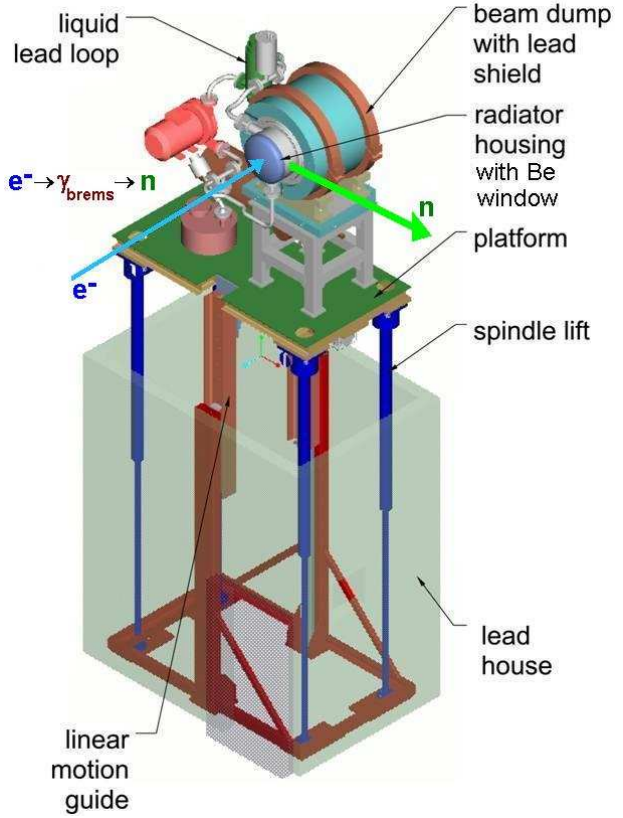
^{56}Fe (n,n'γ) ^{56}Fe

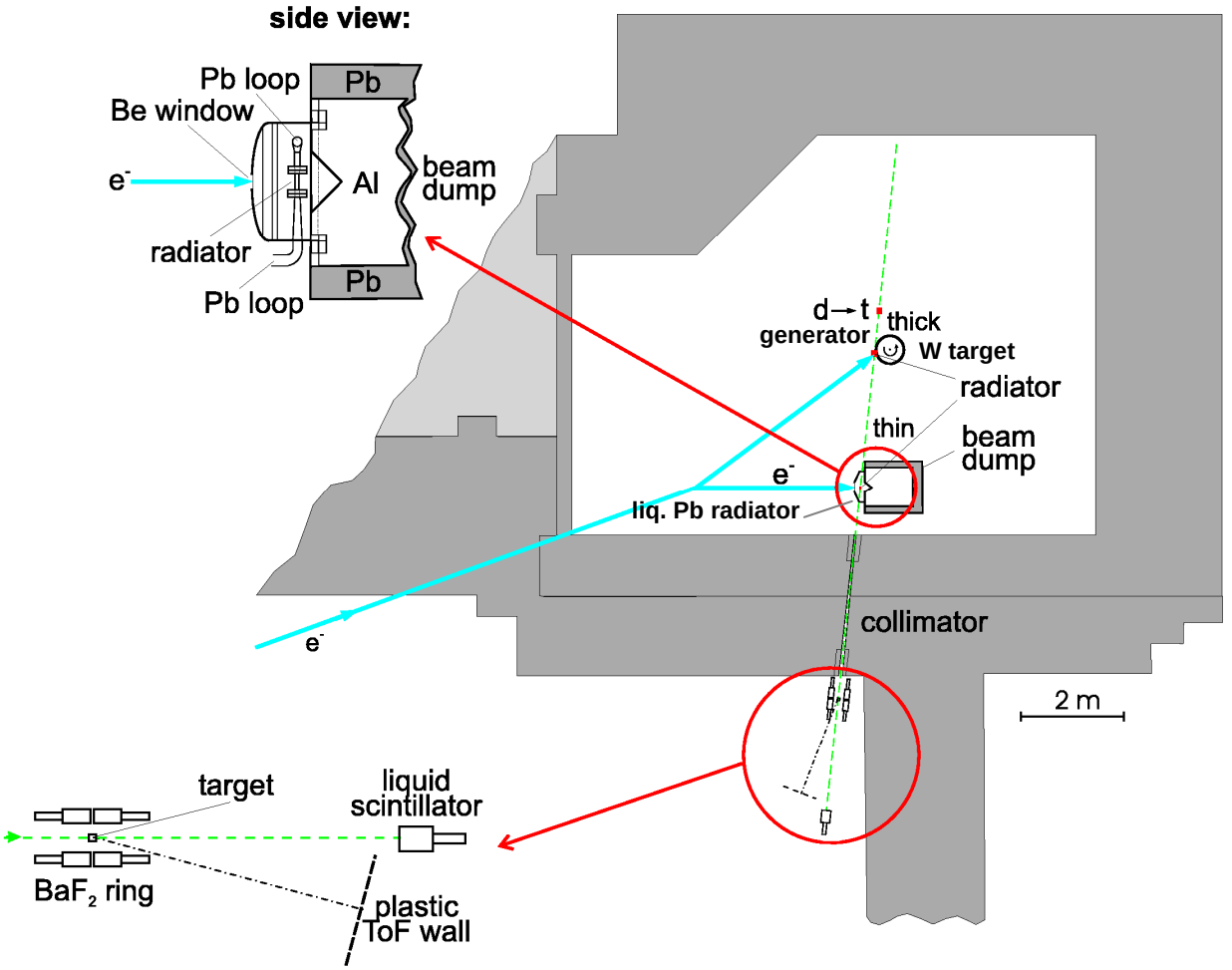
nELBE – neutron facility at ELBE



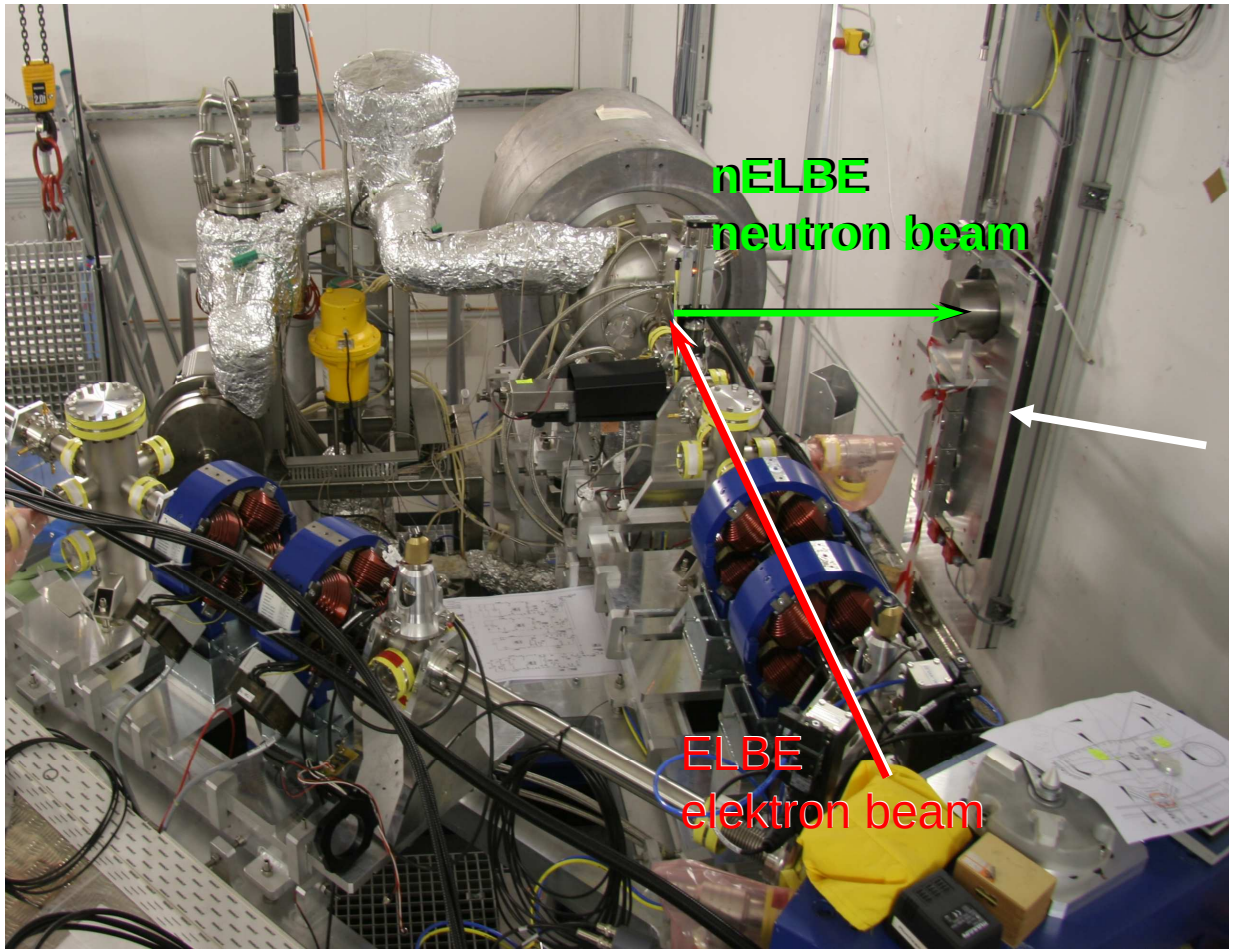
nELBE – neutron facility at ELBE





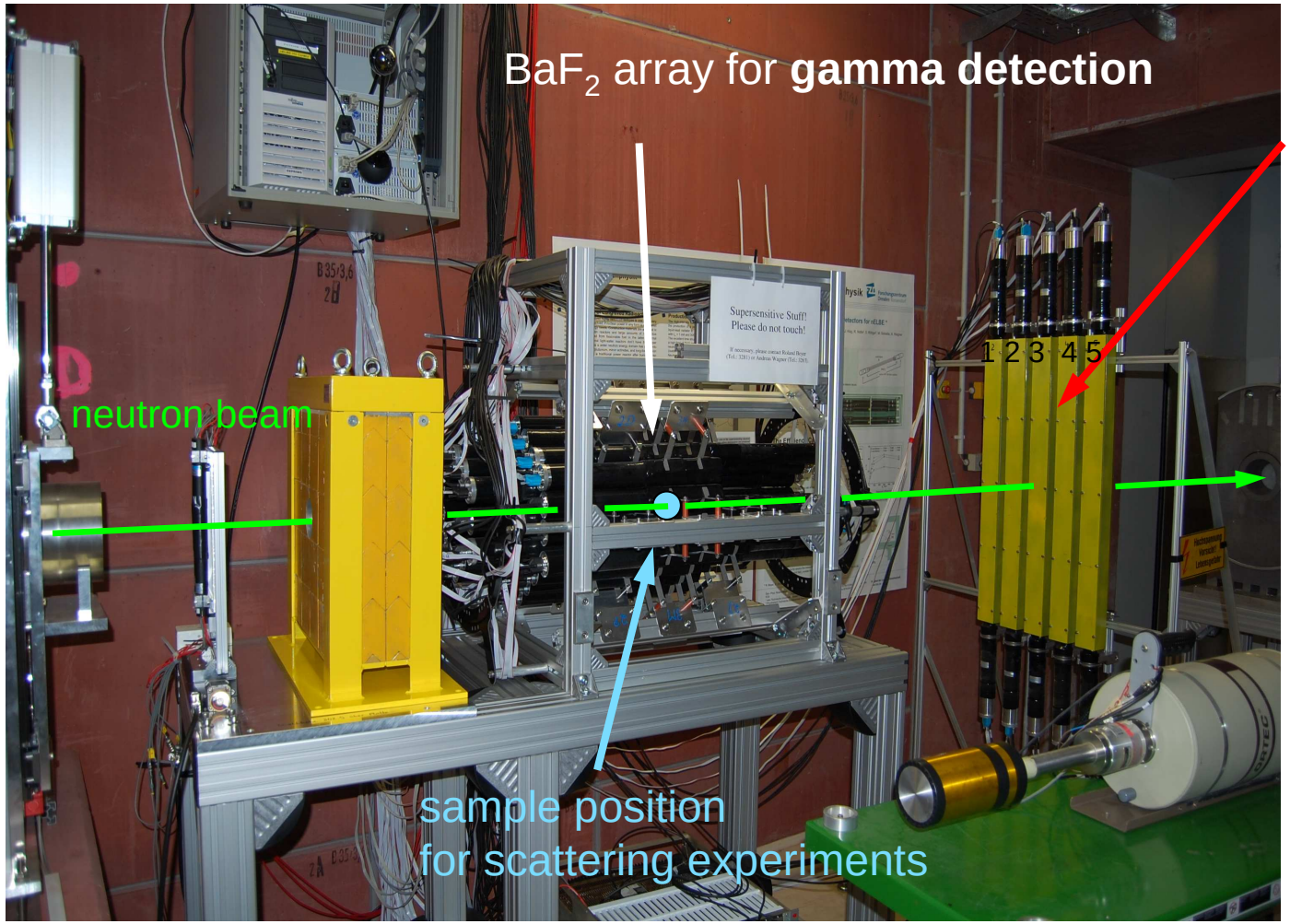


nELBE – neutron production



sample holder for transmission measurements

nELBE – Detector Setup



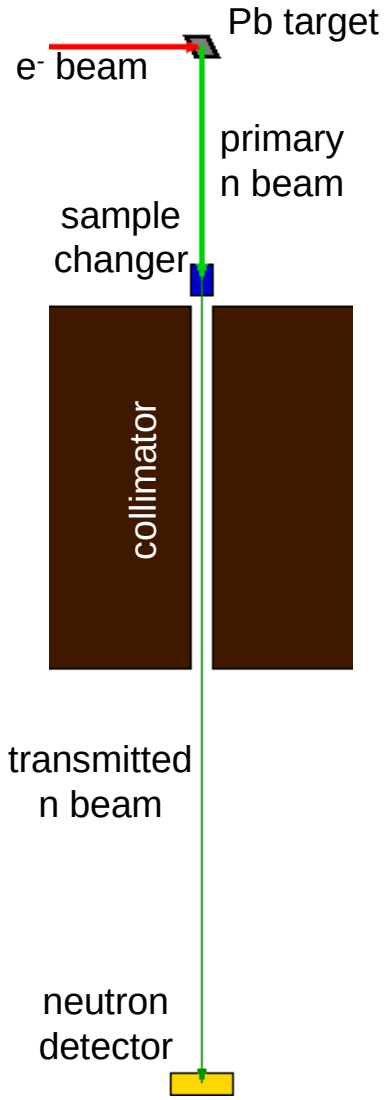
5 plastic scintillators for **neutron detection**

fast detectors for measuring the **time-of-flight**

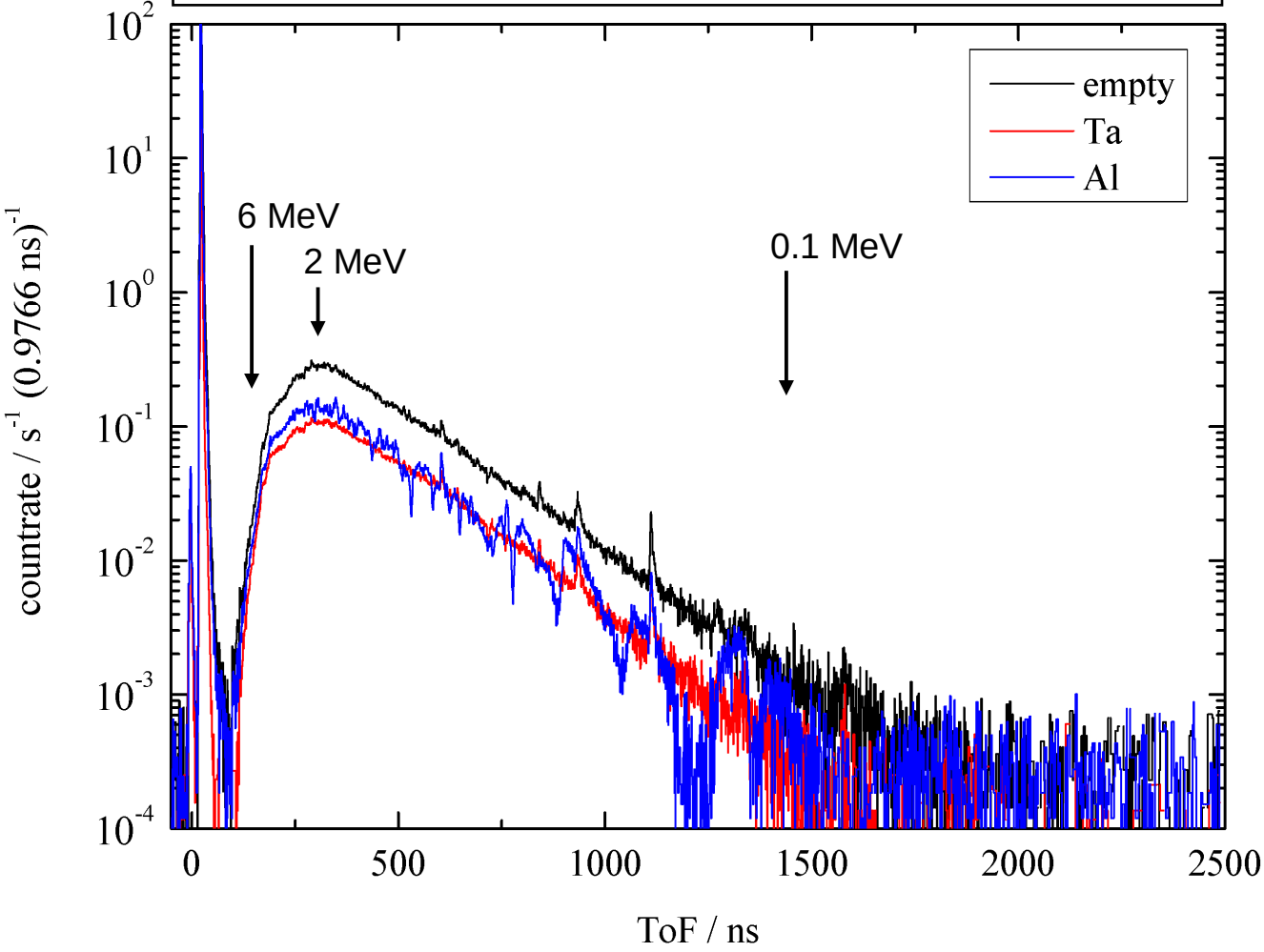
→ time correlation with accelerator pulse structure gives the **neutron energy**

→ e^- pulse width of a few ps allows to use short flight path of about 6 meters

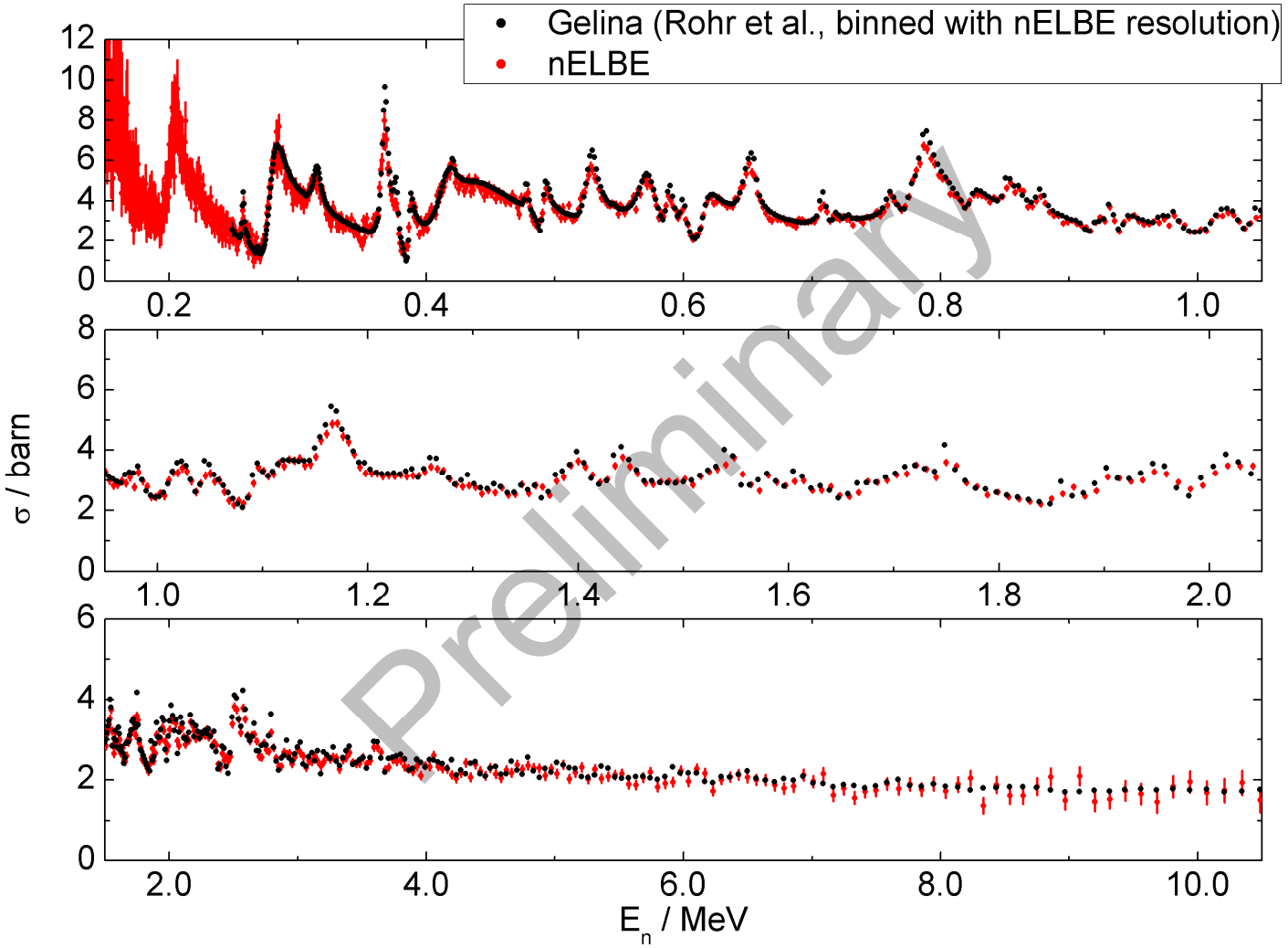
Experimental methods and results - Transmission



$$\sigma_{total} = \sigma_{(n,n)} + \sigma_{(n,n'\gamma)} + \sigma_{(n,\gamma)} + \sigma_{(n,p)} + \sigma_{(n,\alpha)} + \ldots$$



Total neutron cross section of ^{27}Al

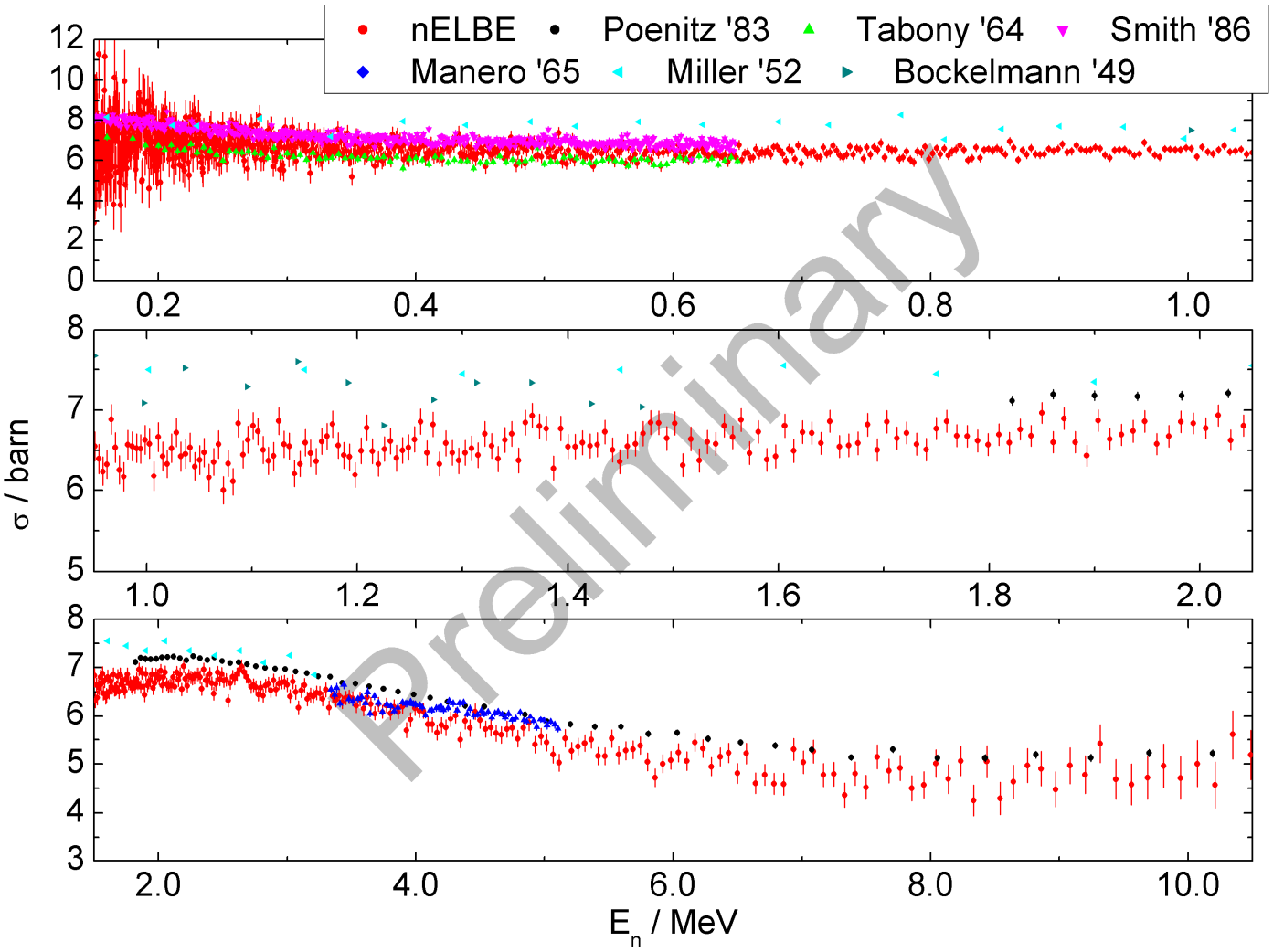


good agreement with high resolution data

→

nELBE works fine for transmission measurements

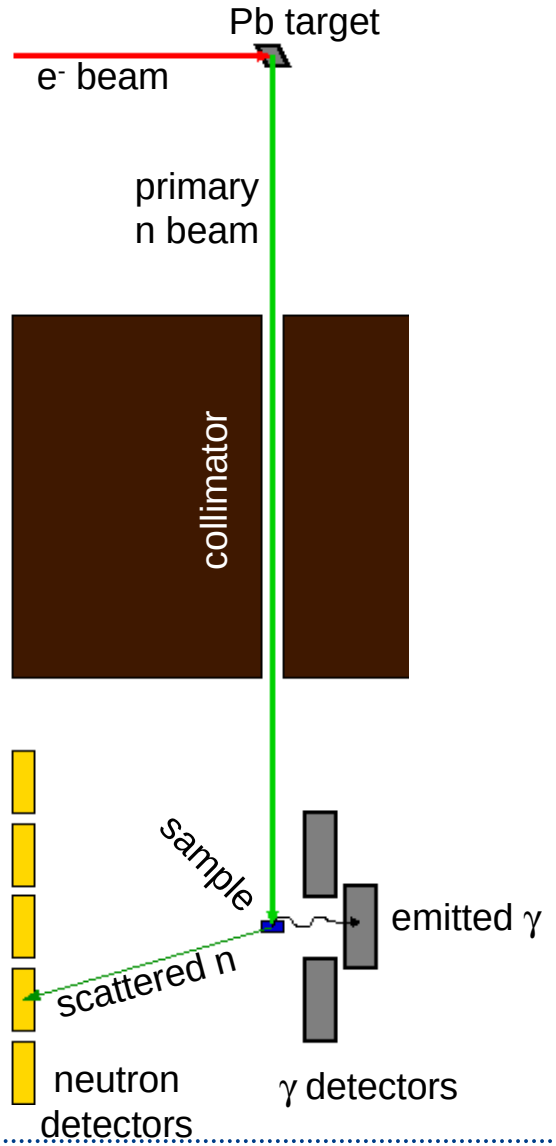
Total neutron cross section of ^{181}Ta



nELBE could close gap between 0.6 and 2.0 MeV

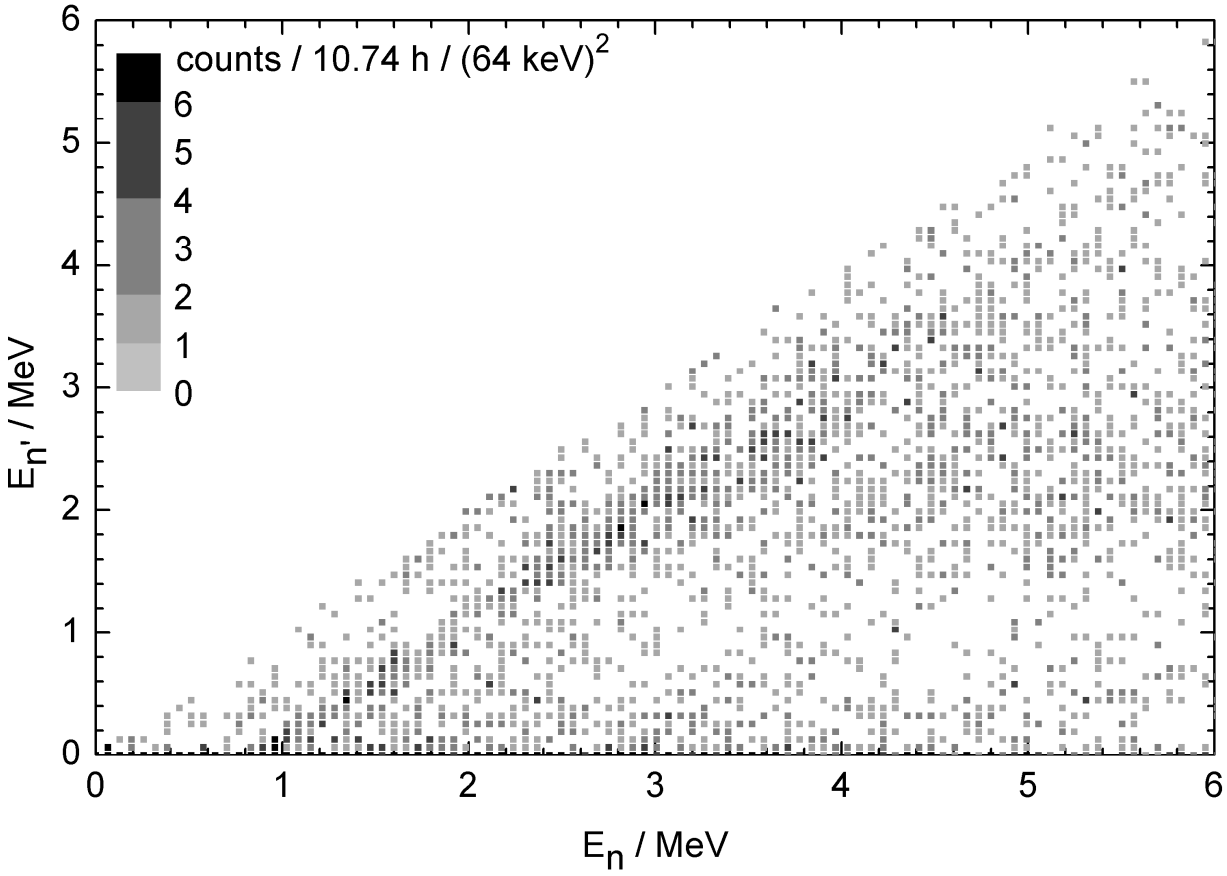
further investi-gations with different sample thicknesses are ongoing

Experimental methods and results – Inelastic Scattering



$$^{56}\mathrm{Fe}(\mathrm{n},\mathrm{n}'\gamma)^{56}\mathrm{Fe} \quad \begin{cases} ^{56}\mathrm{Fe}+\mathrm{n}\rightarrow{}^{56}\mathrm{Fe}^{*}+\mathrm{n}' \\ ^{56}\mathrm{Fe}^{*}\rightarrow{}^{56}\mathrm{Fe}+\gamma \end{cases}$$

$$E_{n,min} = 847\,\mathrm{keV}$$



Summary

- efficient **nuclear waste treatment is needed** to reduce time of disposal significantly

→ **transmutation** of long lived isotopes into short lived ones

- **Generation IV Reactors and Accelerator Driven Systems** are promising sites for transmutation using neutrons
- **data about neutron interaction** with fuel and structural materials **is needed** for simulating and designing those facilities

- **nELBE** delivers the possibility to study nuclear reactions with fast neutrons
- technique for measuring the **total neutron cross section** was successfully proven
- measuring the **inelastic scattering cross section** is possible but needs more improvements

Thanks to all Collaborators

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