GENERATION OF NEUTRONS IN HEAVY EXTENDED TARGETS BY ELECTRONS OF ENERGY FROM 30 MeV TO 1000 MeV

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XIX INTERNATIONAL BALDIN SEMINAR ON HIGH ENERGY PHYSICS PROBLEMS "RELATIVISTIC NUCLEAR PHYSICS & QUANTUM CHROMODYNAMICS"

Dubna, September 29 - October 4, 2008

Outline

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- Target compositions
- SAD as an example of the ADS using 200 MeV electrons
- Comparison of neutron spectra and activities induced by protons and electrons
- Neutron and photon spectra at various energies of electrons
- Conclusion

MOTIVATION

For many research purposes:

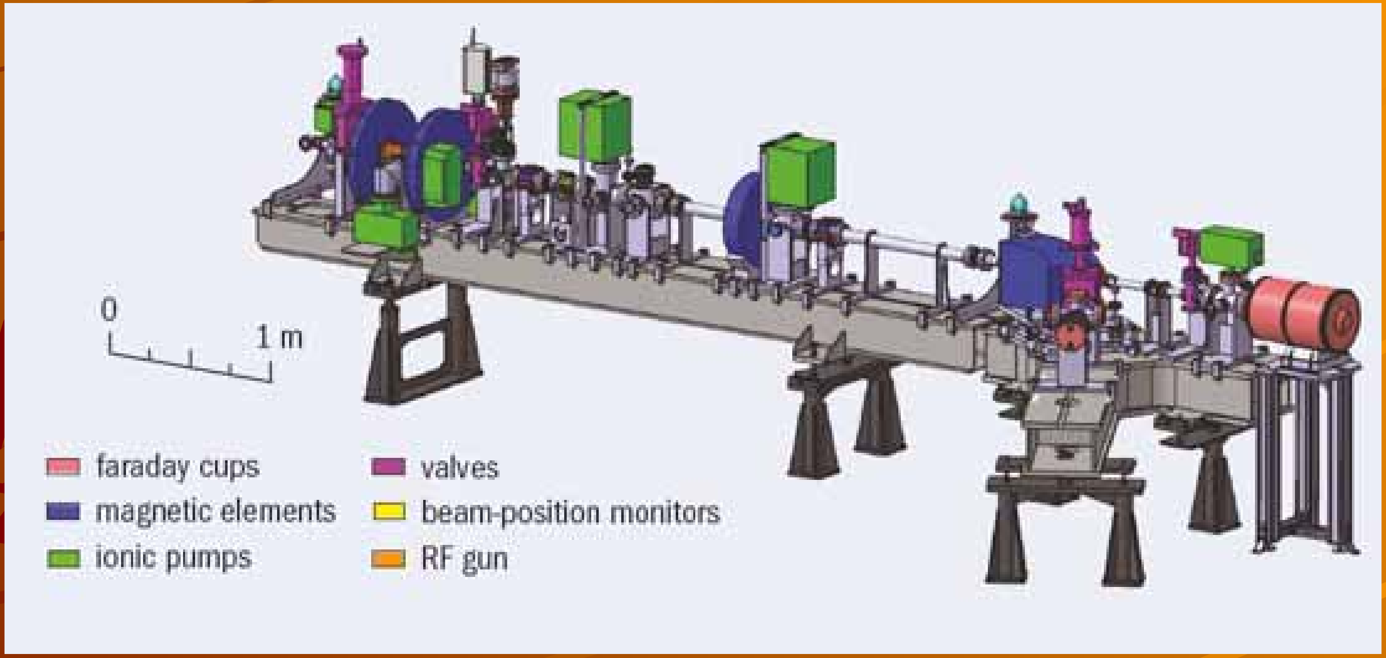
♣ material radiation physics,
♣ radiation protection,
♣ translutation&incineration of radioactive waste
♣ safe subcritical energy production etc

needed are neutrons sources which are:

☼ not too expesive *(to be build in not too rich laboratories),*
☼ flexible enough *(to cover a suitable energy range),*
☼ closed to the optimal ones *(for the investigated problem).*

Electrons linacs as available basic devices of neutrons spallation sources

An example



A new linac facility at the Laboratoire de l’Accélérateur Lineáre, Orsay, 10 MeV (from: CERN Courier, V.48, N.7, September 2008, p.9)

But the question arises: what is

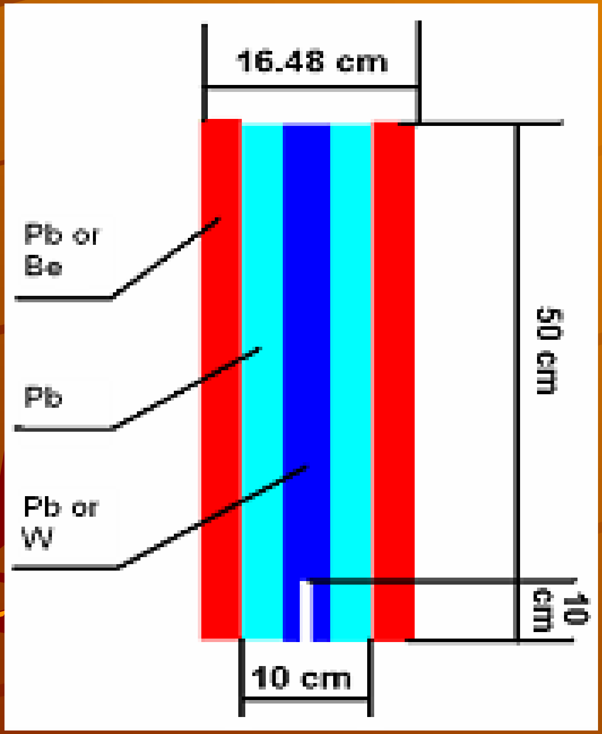
- ♣ the space-energy field of spallation neutrons induced in heavy extended targets by electrons within a large enough energy interval,
- ♣ the neutrons multiplicity,
- ♣ the photons yield.

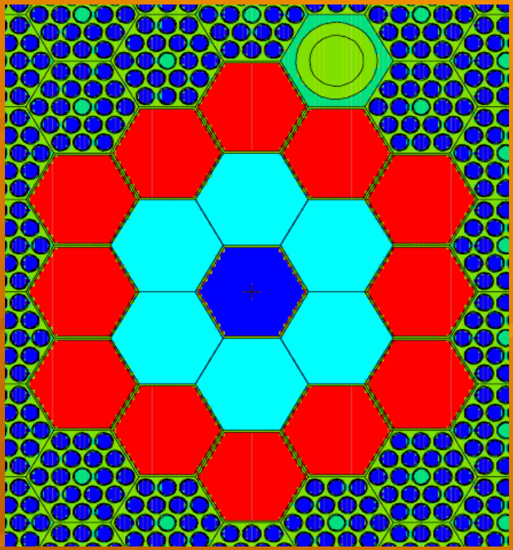
Abstract

- *We present the results of calculation of the space-energy spectra of neutrons generated in different heavy spallation target compositions of W, Pb, Be, MOX by electrons of energy from 15 MeV to 1 GeV. These spectra are compared with the similar ones produced by 1000 MeV protons in the same targets. The conclusion is made that the shape of neutron energy spectra created both by protons and electrons are sufficiently comparable in order to be used as a spallation neutron source for several aims like transmutation and incineration. All calculations have been performed by using MCNPX code.*

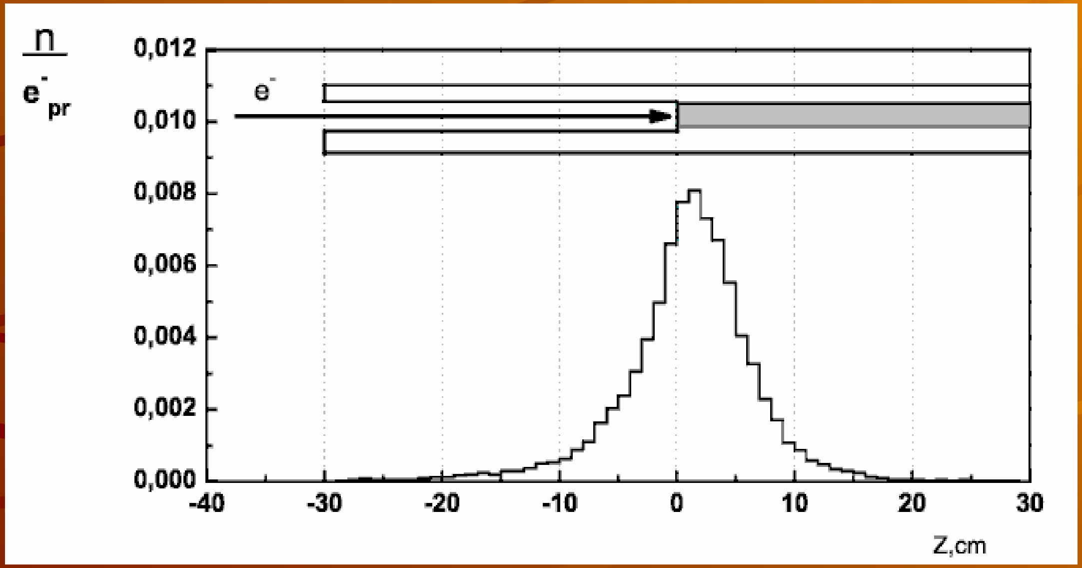
Target composition

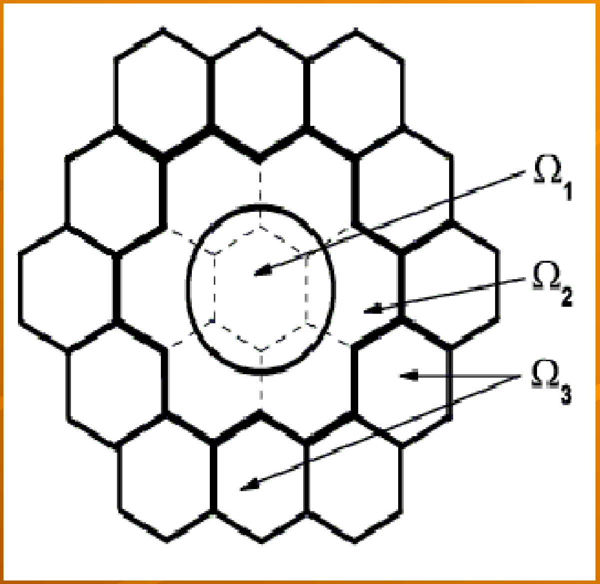
as the core of a subcritical 200 MeV electron driven set-up



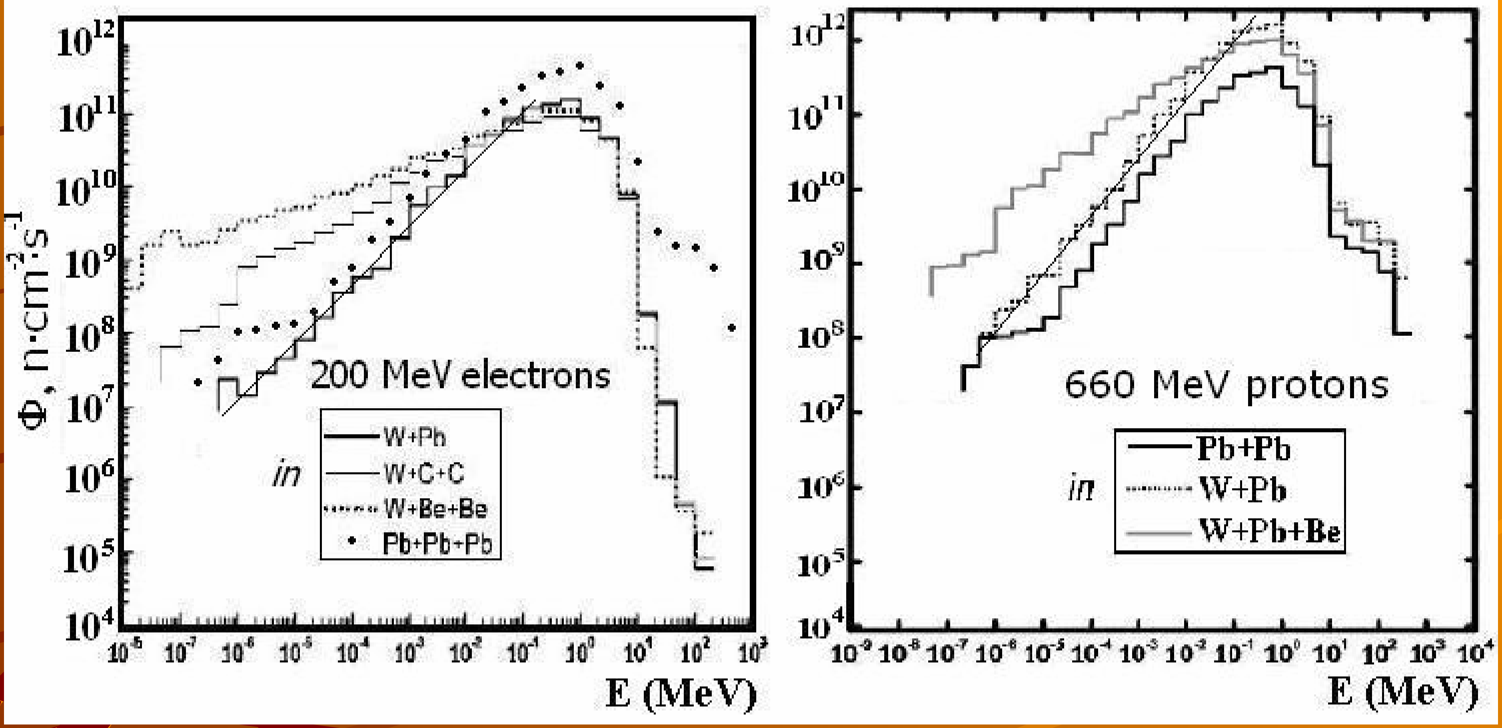


Neutron emission through the side surface of the target with the tungsten insert along the target/200 MeV electrons beam axis.





Comparison with the case of 660 MeV protons



Energy spectra of neutrons produced in W and Pb central target rods of the assembly by 200 MeV electrons (left) and 660 MeV protons (right). Straight lines illustrate the fitting function $(\Delta\Phi/\Delta E) \sim E^{0.81+/-0.01}$.

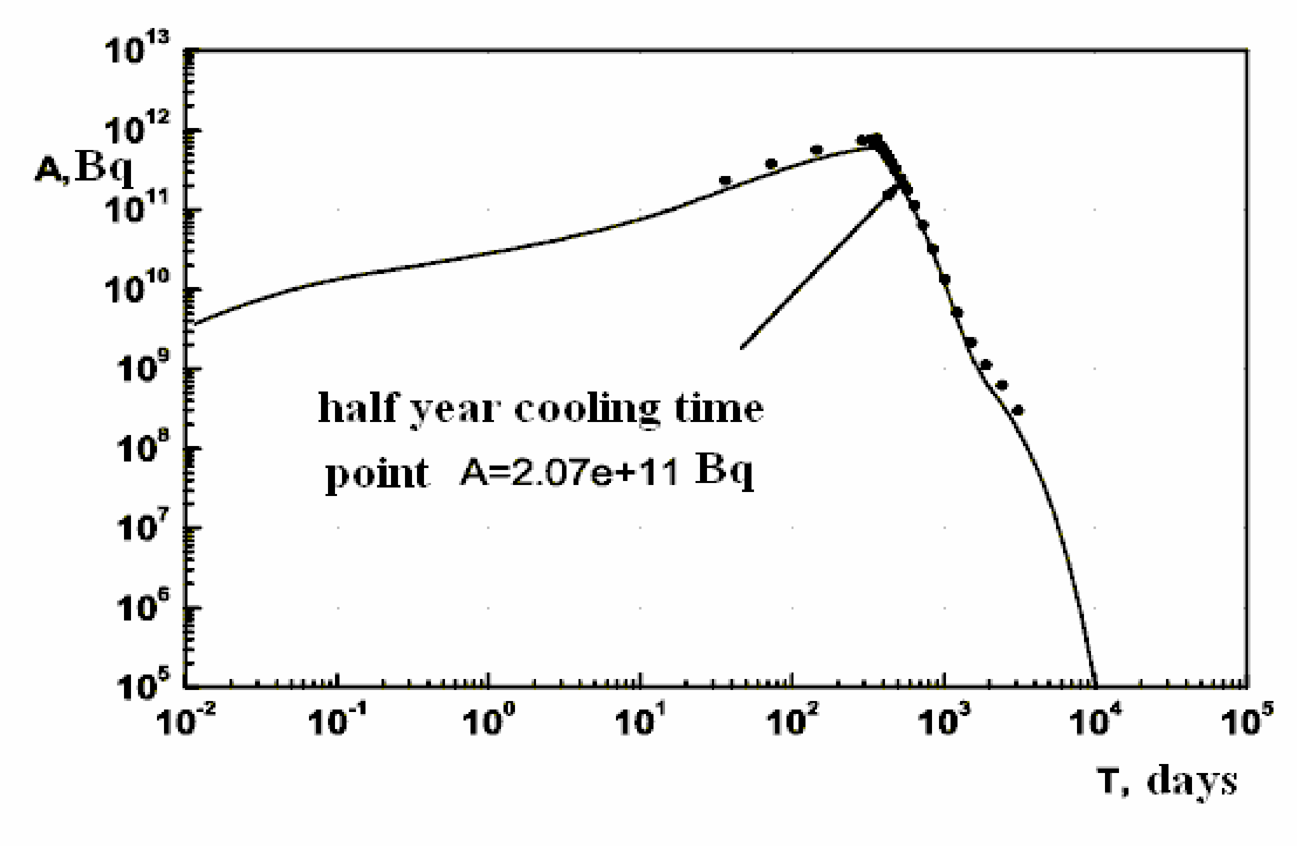
Basic characteristics of the SAD subcritical assembly driven by 200 MeV electrons

Characteristics	Destription
Electron beam power	up to 10 kW
Thermal fission power	up to 10 kW
Fuel elements in fuel assembles	18
Height of a fuel active part	580 mm
Number of fuel assembles	up to 132
Maximal gain factor	K <0.98
Heat-carrier	helium
Reflectors	lead

Activity evolution of tungsten target irradiated by the 200 MeV electron beam

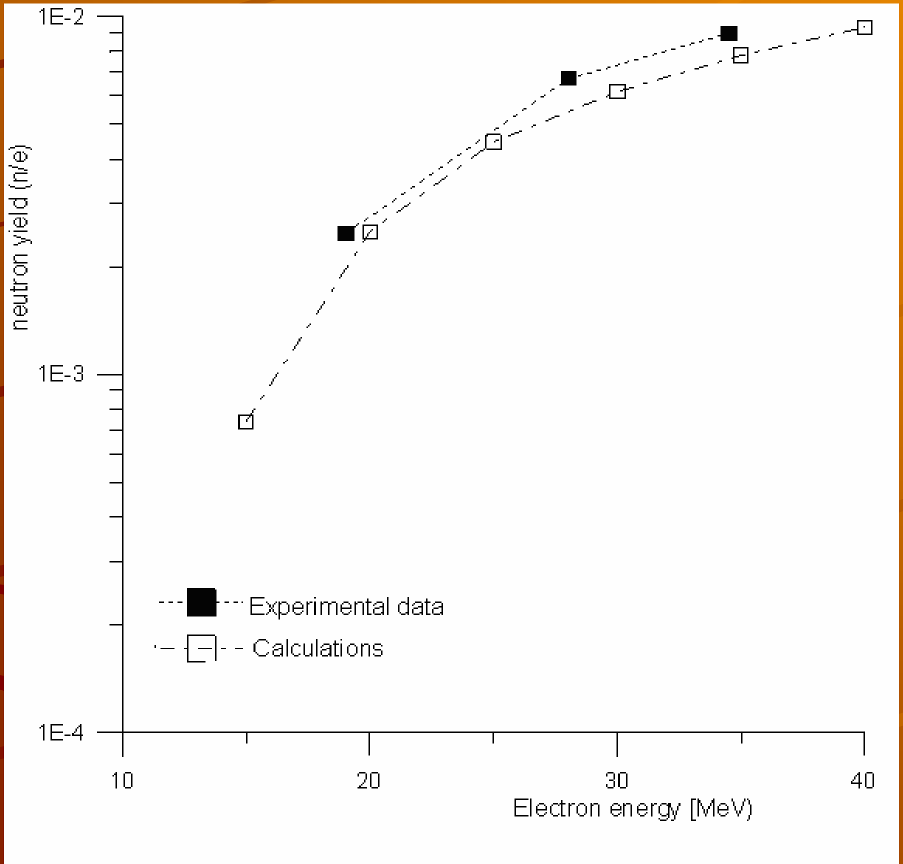
(points show the results of calculation according MCNPX,

solid line – calculation by using TEA code)



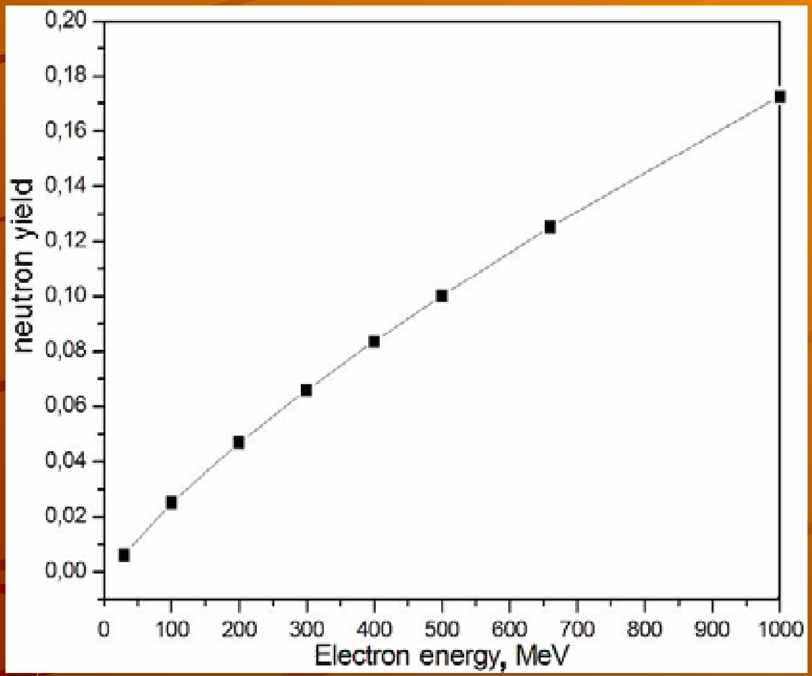
Target	K	Number of fuel assemblies	Φ_{tot}, $n \cdot cm^{2} \cdot sec^{-1}$	P_{heat}, kW
W + Pb	0,974	132	$7,4 \cdot 10^{11}$	10,25
W + C + C	0,974	130	$5,9 \cdot 10^{11}$	8,57
W + Be+ Be	0,975	116	$7,9 \cdot 10^{11}$	11,25

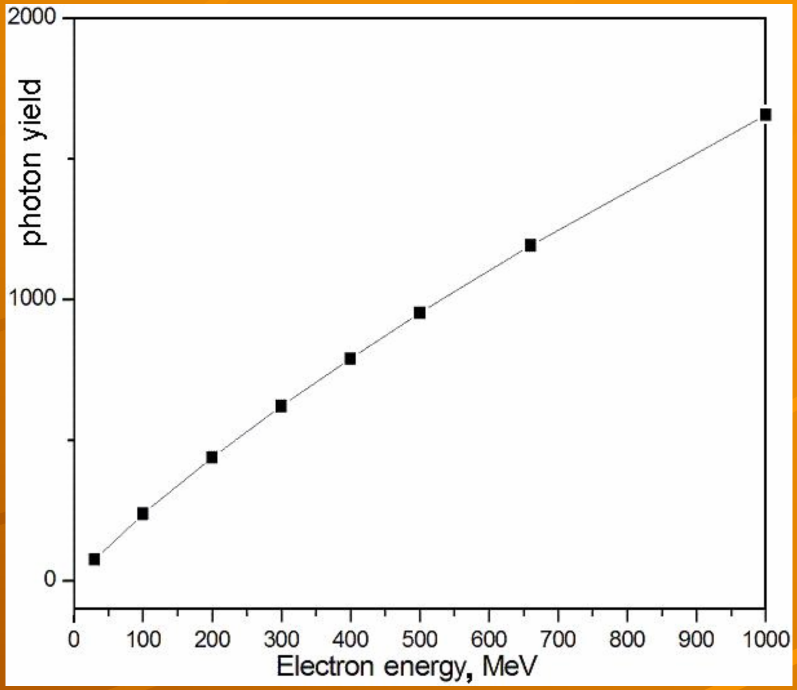
Neutrons yield vs electron energy



Average multiplicity distribution of neutrons (produced by a single electron) of energy from 15 to 40 MeV in the lead target 3.34 cm along and 3.34 cm in diameter.

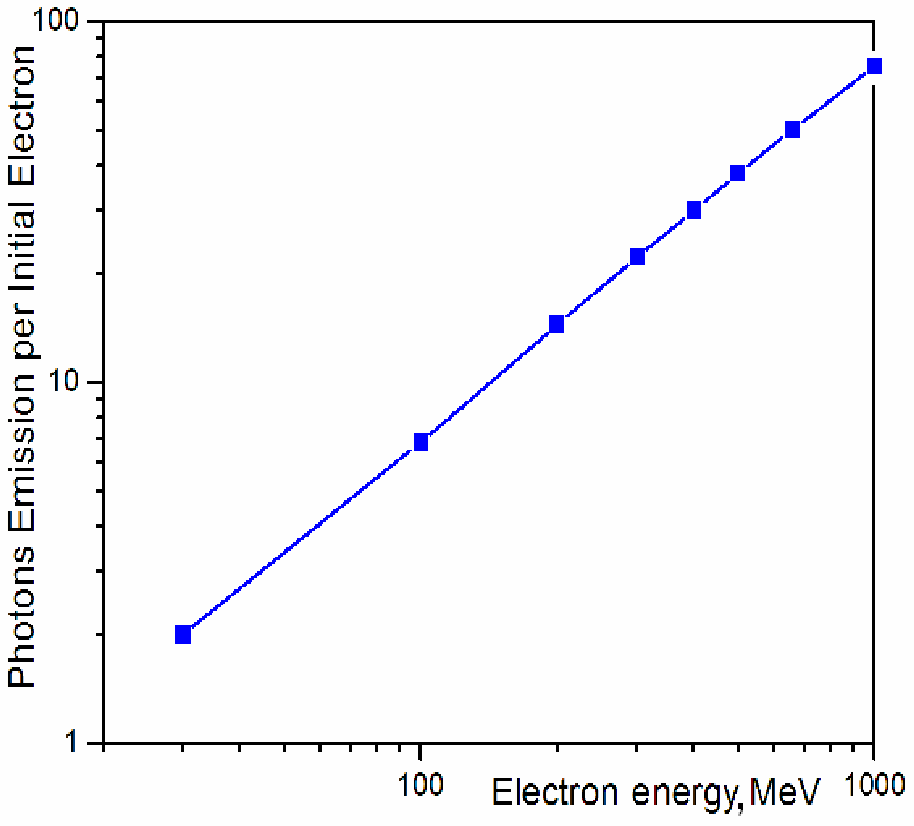
Neutrons and photons yield vs electron energy





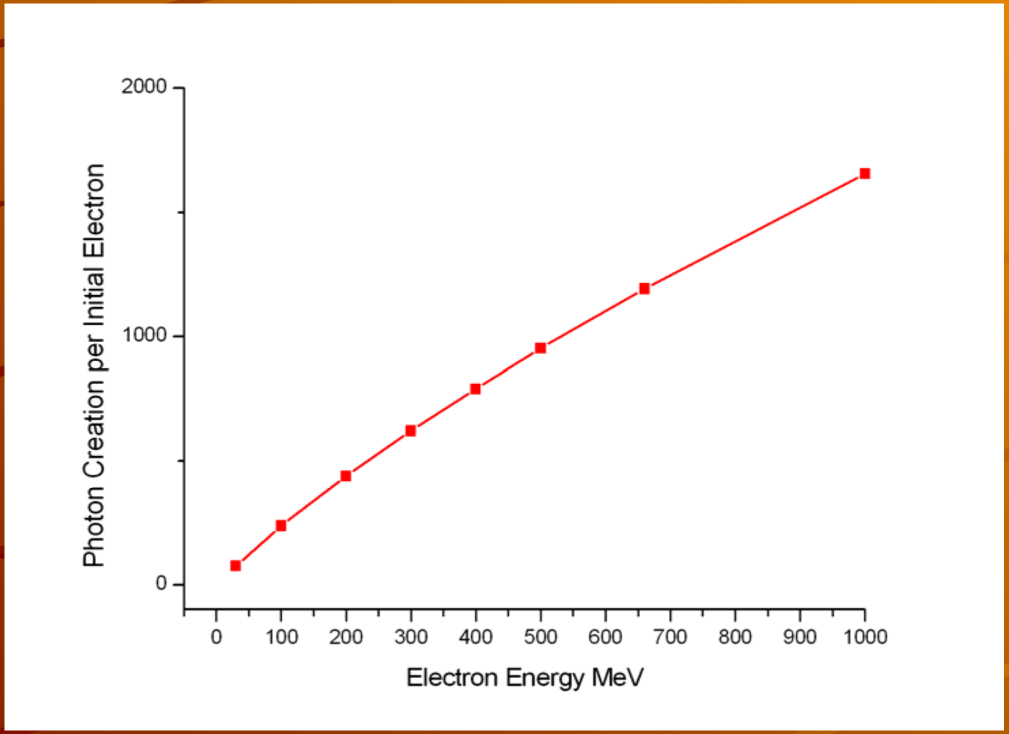
Average multiplicity distribution of neutrons (left) and photons (right) produced by single electrons of energy from 30 to 1000 MeV in the lead target 3.34 cm along and 3.34 cm in diameter.

Emission of escaping photons



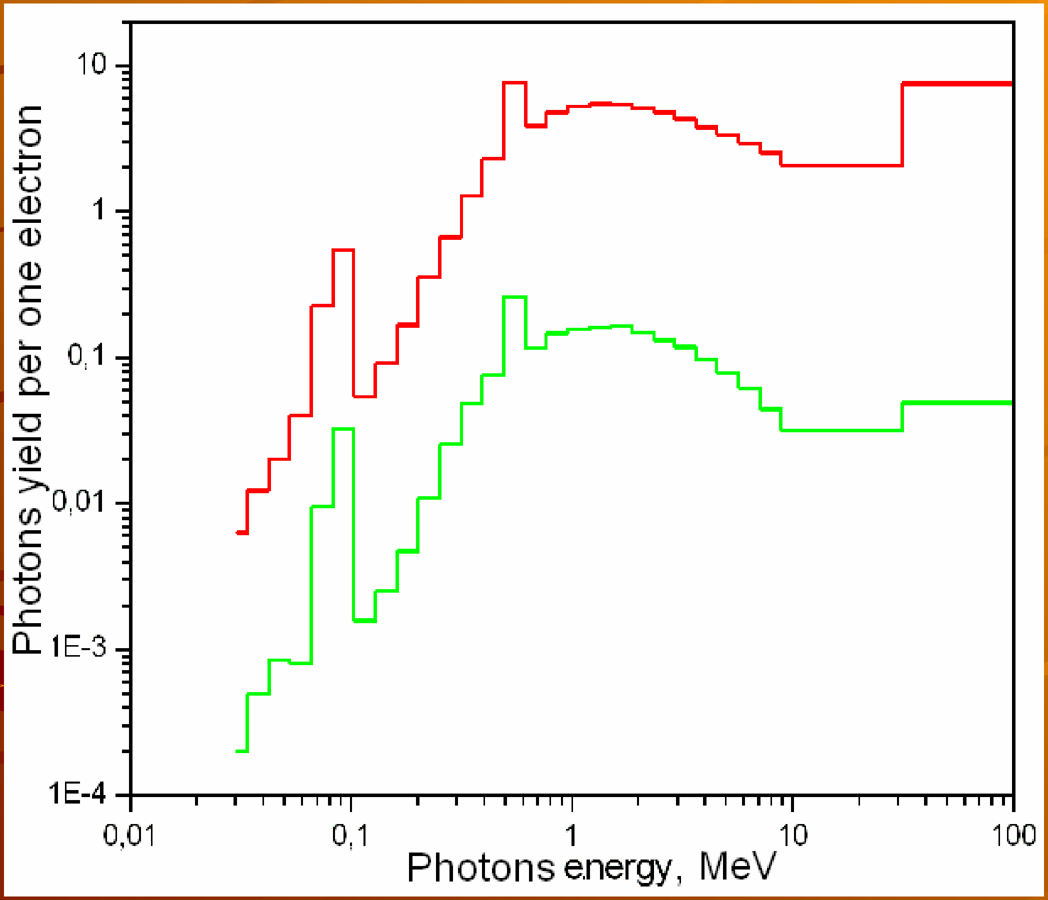
Escaped photons produced by a single electron of energy fron 30 MeV to 1000 MeV in the lead target 3.34 cm along and 3.34 cm in diameter.

Photons emission



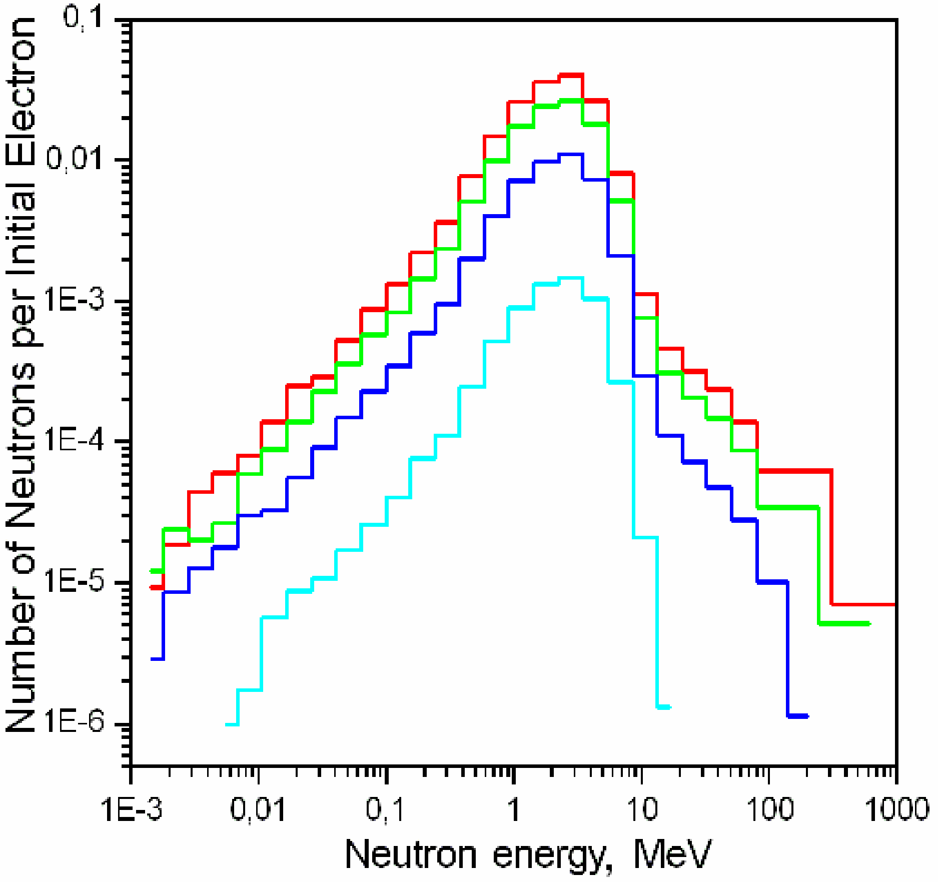
Average multiplicity distribution of photons (produced by a single electron) of energy from 30 to 1000 MeV in the lead target 3.34 cm along and 3.34 cm in diameter.

Energy spectrum of photons



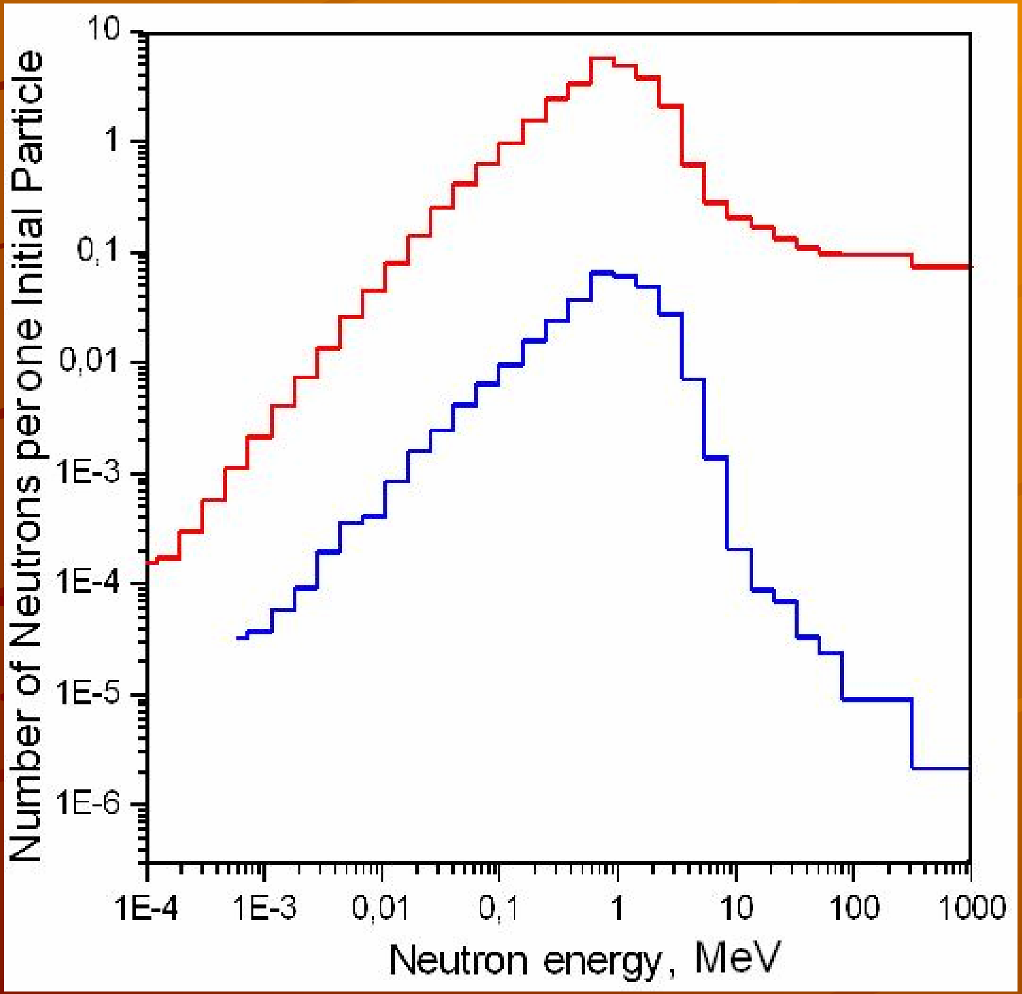
Spectrum of photons produced by a single electron of energy 30 MeV (green) and 1000 MeV (red) in the lead target 3.34 cm along and 3.34 cm in diameter.

Neutrons energy spectra



Spectrum of neutrons produced by a single electron of energy 30, 200, 600, 1000 MeV in the lead target 3.34 cm along and 3.34 cm in diameter.

Comparison of neutrons spectra for initial protons and electrons



Spectra of neutrons produced by single electrons (blue) and protons (red) of energy 1000 MeV in the lead target 60 cm along and 60 cm in diameter.

Protons of 1 GeV on lead target 60cm*60 cm

- **proton creation**
- source 1
- nucl. interaction 4.4526
- total proton creation 5.4526
- escaped 6.6204E-02
- **neutron creation**
- nucl. interaction 30.195
- photonuclear 2.0632E-04
- (n,xn) 3.9496
- total neutron creation 34.147
- escaped 28. 475

- **photon creation**
- nucl. interaction 16.531
- from neutrons 40.015
- bremsstrahlung 112. 02
- pair-annihilation 6.8193
- photonuclear 2.21E-04
- 1st fluorescence 81.477
- 2nd fluorescence 16.725
- total photon creation 273.58
- escaped 4.3875E-01

Electrons of 1 GeV on lead 60cm*60 cm

- **neutron creation**
- nucl. interaction 3.2696E-03
- photonuclear 3.1688E-01
- (n,xn) 2.4430E-03
- tot. neutron creation 3.226E-01
- escaped 3.1686E-01
- **proton creation**
- nucl. interaction 1.1576E-04
- (gamma, N ch. part. produced) 1.358E-03
- tot.proton yield 1.474E-03
- escaped 0

- **photon creation**
- nucl. interaction 3.2168E-03
- from neutrons 3.2064E-01
- bremsstrahlung 2.1867E+03
- pair-annihilation 1.2003E+02
- Photonuclear 5.1838E-01
- electron x-rays 3.3744E+01
- 1st fluorescence 6.8814E+02
- 2nd fluorescence 1.2564E+02
- photon creation 3.1550E+03
- escaped 1.2563E-02

Conclusion

- Neutron energy spectra in both cases, electrons and protons, are very similar in the region of lower energies (0-10 MeV) for the same target composition.

- The activity of a lead target for proton beam is equal to $4 \cdot 10^{10}$ Bq after half a year of shut down.

- The activity of the tungsten target for 200 MeV electron beam with power of 10 kW reaches about $2 \cdot 10^{11}$ Bq which is approximately 5 times larger than the activity induced by the 660 MeV proton beam with power of 1 kW.
- The yield of produced neutrons constitute about 0.32 neutrons per one electron whereas the average multiplicity of neutrons generated by protons at the same kinetic energy of 1 GeV, and in the same lead target of 60 cm along and 60 cm in diameter, is 34 neutrons per proton.

- The activity of the target for electron beam is approximately 25 times larger than the activity induced by the proton beam for similar installation with fission power 50 kW.

General conclusion

Advantages (A) and disadvantages (D) of the use of electrons accelerators over hadronic ones:

- (A) relative cheapness, simplicity and flexibility, similar shape of neutrons energy spectra, and the target activity is significantly larger.
- (D) neutrons yield is of about two orders of magnitude less and the activity of the target for electron beam is approximately 25 times larger than the activity induced by the proton beam for similar installation with fission power 50 kW.

Thank you

for

your attention