Transmutation of spent nuclear fuel

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Accelerator driven subcritical reactors - ADSR

1. Spent nuclear fuel
   1. 11 500 tons of spent fuel yearly
   2. Storage, reprocesing or transmutation
   3. Transmutation is possible using ADSR
2. ADS
   1. Subcritical core, proton beam accelerator, spallation target
   2. Inherent safety
   3. Fast neutron spectrum

Basic scheme of ADSR

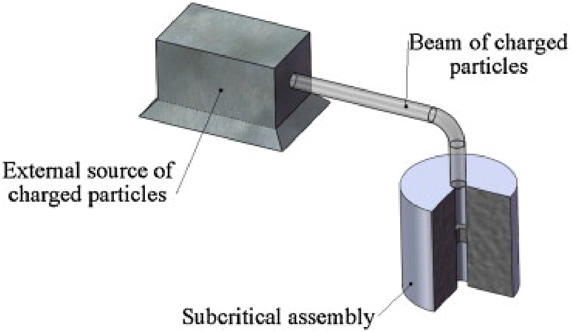
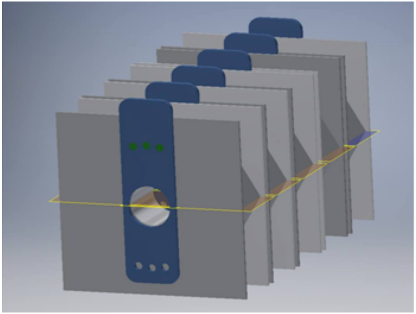


Figure: Scheme of Accelerator Driven Subcritical Reactor [1]

QUINTA

1. Since 2010
2. 350 x 350 x 700 mm^3, 512 kg of natural Uranium
3. 5 section, 298 cylinders, 1.72 kg natural Uranium
4. 1st section = 54 cylinders, 2nd – 5th = 61 cylinders



Model of QUINTA

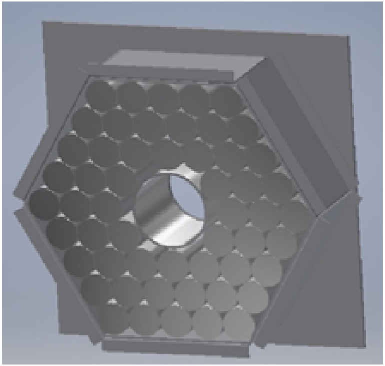


Figure: First section

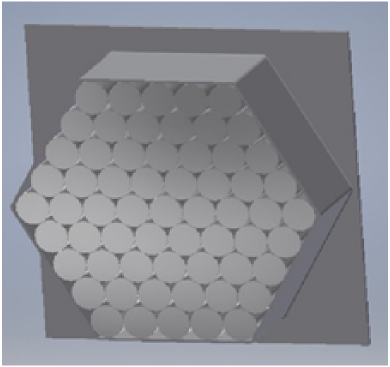
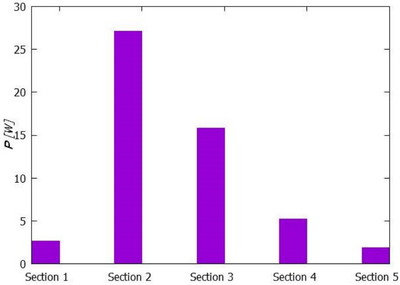


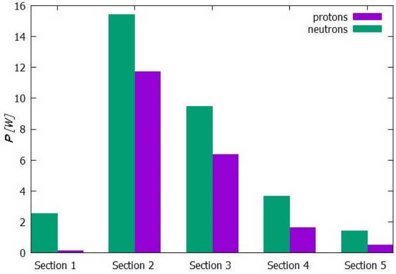
Figure: Section two to five

Thermal energy production in each section

1. Data calculated by MCNP6
2. Experiment performed in May 2016

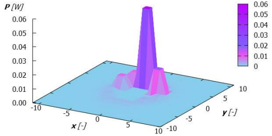
Figure: Power producing in individual sections



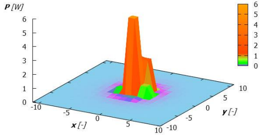


Thermal power production by **protons** per section

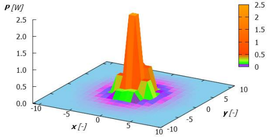
Power production of the 1st section - protons



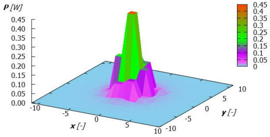
Power production of the 2nd section - protons



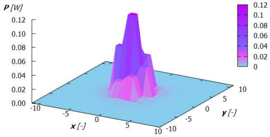
Power production of the 3th section - protons



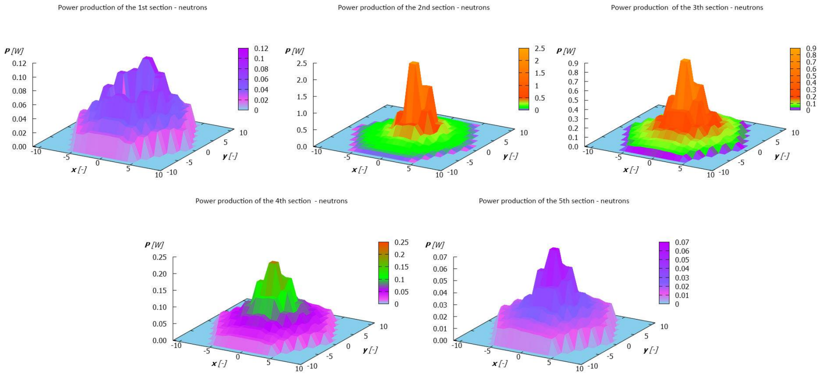
Power production of the 4th section - protons



Power production of the 5th section - protons



Thermal power production by **neutrons** per section



Thermal analysis results

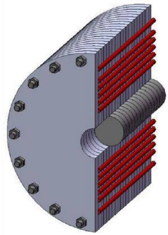
Integral number of incident protons was estimeted by activation analysis.

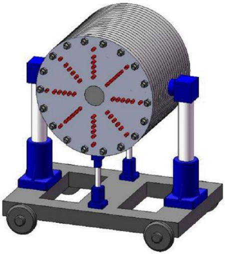
1. The number of protons : $4.88 \cdot 10^{15} \rightarrow 2.77 \cdot 10^{11}\ s^{-1}$
2. Time of irradiation : 294 min
3. Energy : 660 MeV

Total beam power : 29.25 W
Total thermal power released inside the Quinta: 52.76 W
Ratio: 1.8

Quasi infinite target - BURAN

1. Successor of QUINTA
2. 20 tons of depleted uranium
3. Diameter - 1.2 m, Length - 1 m
4. Estimated start - spring 2018





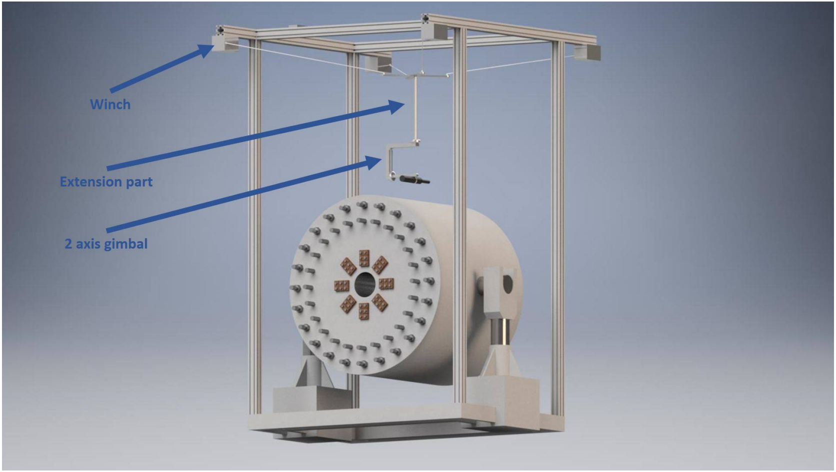
Neutron measurement

1. Neutron detector ThermoFisher FHT 752
2. Based on Boron Trifloride tube
3. High gamma-ray rejection
4. Weight – 800 g

Automation of neutron field measurement

1. Need for measuring front, back and upper parts of the BURAN target
2. Detector needs to be perpendicular to surface
3. Concept based on cable driven manipulator and 2 axis gimbal
4. Controlled from remote PC

Concept of manipulator for neutron field measurement



Known problems of the concept

1. All electronic, drivers included, need to be behind shielding
2. No common semiconductor based sensors for feedback control can be used

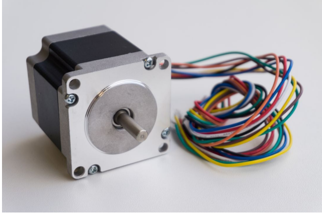
Drives for manipulator

1. Winch motors

   Torque > 1.5 Nm Best option – stepper motors

2. Gimbal motors

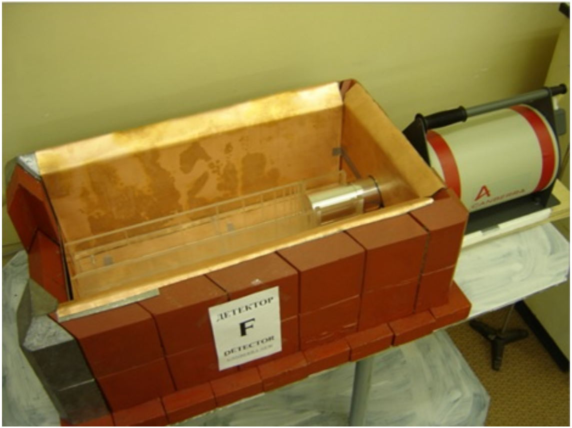
   1. Not enough information for accurate torque calculation
   2. Best options
      1. Stepper motors
      2. BLDC motors



Gamma spectroscopy

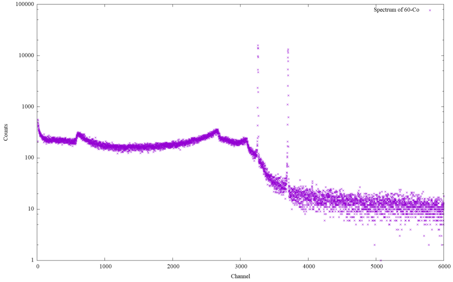
1. Method for identification of radionuclides by analysis of the gamma-ray energy spectrum produced in a gamma-ray spectrometer
2. HPGe detectors
   1. Calibration of detector
   2. Measurement of standards gamma-ray sources (^{60}Co, ^{88}Y, ^{228}Th, ...)
   3. Full peak efficiency
   4. Total efficiency

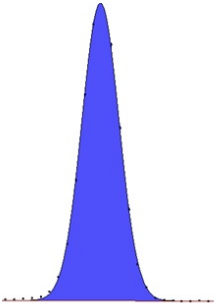
HPGe detector in lead shelding



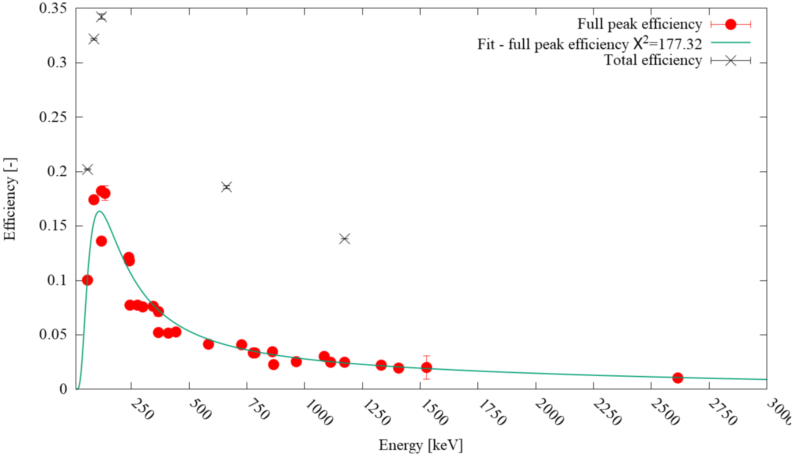
Data analysis

1. Spectrum from HPGe
2. Peak approximation
   1. Gaussian function
   2. Peak area, energy



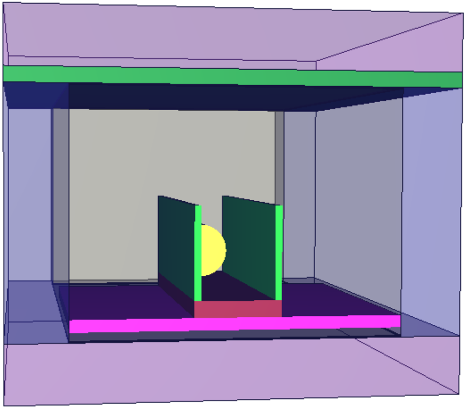


Experimental efficiency results



MCNP simulation

1. Stochastic code for simulation of particle transport
2. Based on the Monte Carlo method



Detector details

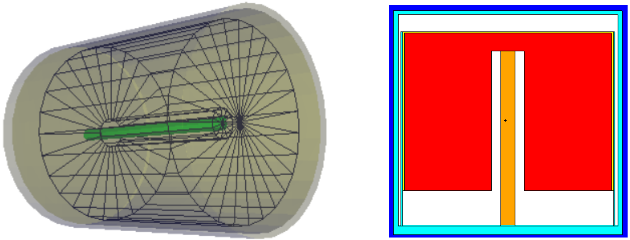


Figure: Detail of the HPGe detector (VISED Visual Editor)

Simulation

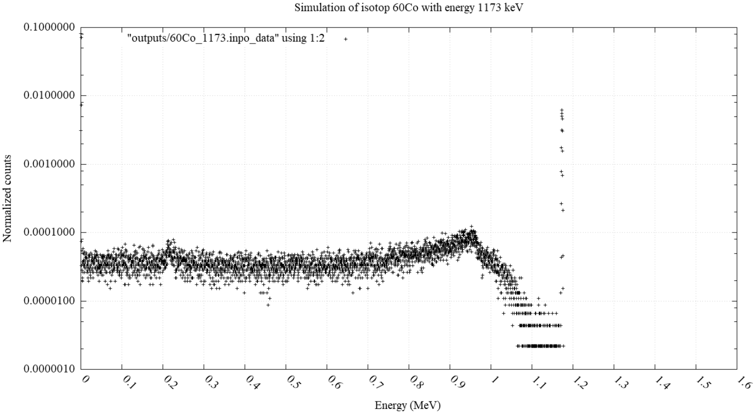
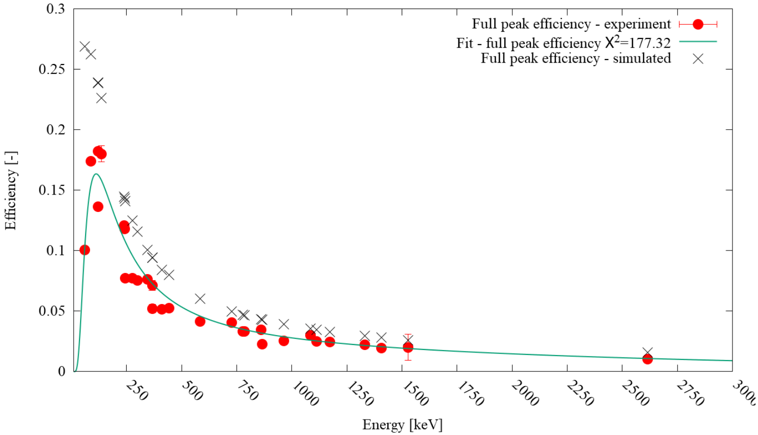


Figure: Simulation of isotope ^{60}Co with energy 1173 keV

Comparison of simulation and experiment



Ruby

1. Scripting language
2. Connection between GNU plot and Ruby
3. Application of processing datas using Ruby

```
Dir["data/*.inpo"].each do |filename|
k=0
        system("cd..")
        filename=filename.split("/")[1]
        puts filename
        File.open("outputs/#{filename}_data", 'w') do |f|
                row=nil
                File.open("data/#{filename}").each do |line|
                        k=k+1
                        if line.include?("this tally is modified by   ft   ge")
                                row=k
                        end
                end
```

Conclusion

1. Detector efficiency determination
2. 3D visualisation of detector
3. Simulations of efficiency and comparison with experiment
4. Heat generation analysis inside the QUINTA assembly
5. Concept and 3D model of manipulator for neutron field measurement
6. The biggest benefit for us is learning new information

References

- ZAVORKA, Lukáš. *Transmutation of Actinides Using Spallation Reactions.* Prague, 2015. Czech Technical University in Prague.
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Thanks for your attention

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