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Fast Neutron Activation Analysis

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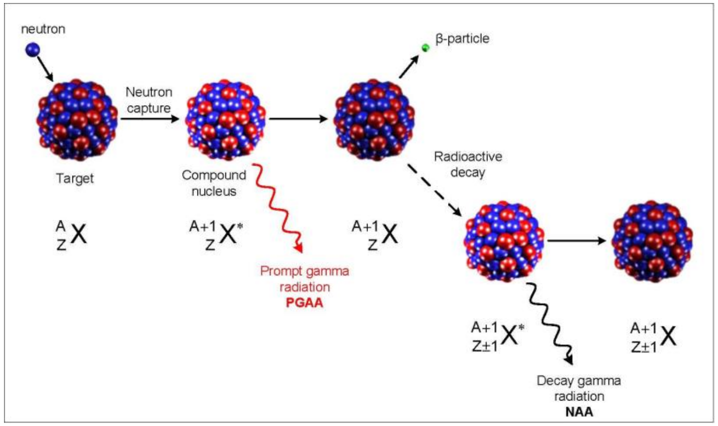
Neutron Activation Analysis

- Performs both qualitative and quantitative multi-element analysis in samples from a wide range of materials
- Recognized as the "reference analytical method"
- Typically, performed with **thermal neutron capture reactions** at research reactor facilities due to the very high sensitivity achieved for many elements
- Can also be performed at particle accelerator produced neutron beams utilizing **fast neutron threshold reactions**



Scope

Fast Neutron Activation Analysis (FNAA) at particle accelerators is limited by:

- Lower neutron fluence, as compared to research reactors
- Lower cross sections of the neutron threshold reactions used in analysis
- Short irradiation times due to finite target life
- Interfering reactions

Scope of this work was to investigate and optimize the FNAA capabilities of the NCSRD Tandem accelerator facility

Method

- Simulations performed using Neutron Activation Analysis advanced Prognosis and Optimization code NAAPRO
- Samples representing biological (IAEA A-13) and geological (IAEA Soil-7) materials
- 14 MeV neutron beam (10^{10} $cm^{-2} \cdot s^{-1}$)
- HPGe detector of 80% relative efficiency
- Several Irradiation-Cooling-Measurement time cycles tested

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Irradiation time	60 s	300 s	0.5 h	3 h	24 h
Cooling time	60 s	300 s	0.5 h	3 h	24 h
Measurement time	60 s	300 s	0.5 h	3 h	24 h

Results

IAEA SOIL-7

Cycle	Element	C (ppm)	Reaction	Energy (keV)	MDL (ppm)
1	Si	180000	$^{29}Si(n,p)^{29}Al$(98.95%) + $^{30}Si(n,d)^{29}Al$(1.05%)	1273.368	2.01E+03
2	Ca	163000	$^{48}Ca(n,g)^{49}Ca$	3084.4	2.44E+03
4	Ca	163000	$^{43}Ca(n,p)^{43}K$(80.99%) + $^{44}Ca(n,np)^{43}K$(15.28%) + $^{44}Ca(n,d)^{43}K$(3.68%) + $^{46}Ca(n,a)^{43}Ar(b-)^{43}K$(0.05%)	396.861	4.13E+04
4	Cd	1.3	$^{116}Cd(n,p)^{116}Ag(B-)$ $^{116}Cd(n,a)$ $^{113}Pd(b-)$ $^{113m}Ag(IT)^{113}Ag$	298.6	1.96E-01
5	As	13.4	$^{75}As(n,2n)^{74}As$	634.78	5.40E+00
5	Ni	26	$^{58}Ni(n,2n)^{57}Ni$	1377.63	9.59E+00
5	Sb	1.7	$^{123}Sb(n,2n)^{122}Sb$(99.82%) + $^{121}Sb(n,g)^{122}Sb$(0.17%) + $^{121}Sb(n,g)^{122m}Sb(IT)^{122}Sb$(0.01%)	564.24	6.51E-01

Results

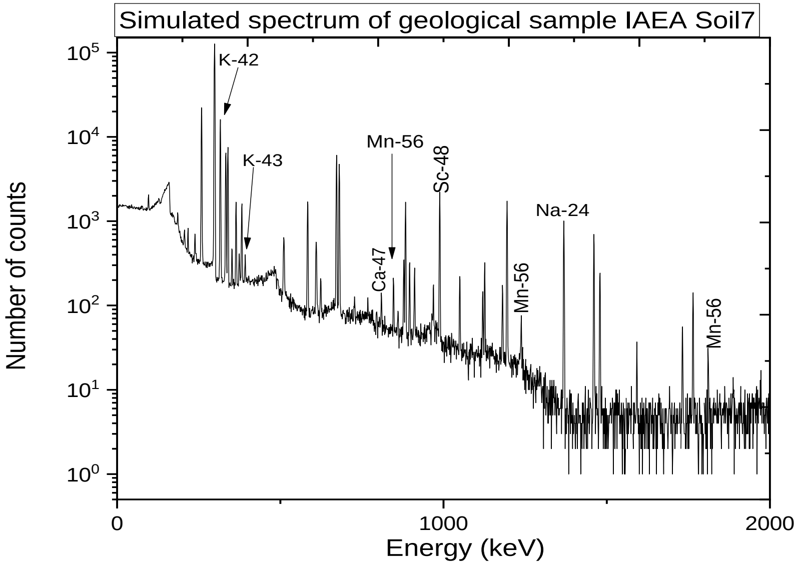
IAEA A-13

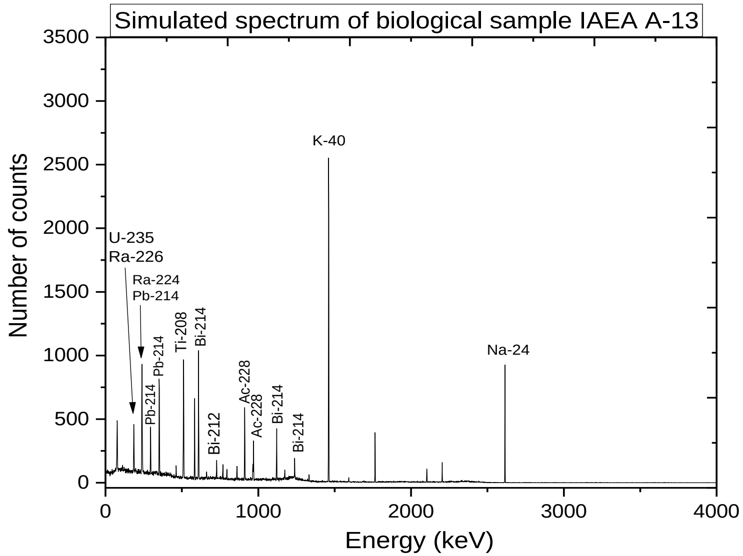
Cycle	Element	C (ppm)	Chain	Energy (keV)	MDL (ppm)
1	P	940	31P(n,a)28Al	1778.85	3.09E+01
2	K	2500	$^{41}K(n,a)^{38}Cl$(74.67%) + $^{41}K(n,a)^{38m}Cl(IT)^{38}Cl$(25.33%)	2167.405	1.39E+03
3	Fe	2400	$^{56}Fe(n,p)^{56}Mn$(99.78%) + $^{57}Fe(n,np)^{56}Mn$(0.19%) + $^{57}Fe(n,d)^{56}Mn$(0.02%)	846.754	1.69E+01
3	Mg	99	$^{24}Mg(n,p)^{24m}Na(IT)^{24}Na(b-)$ $^{24}Mg(n,p)^{24m}Na(IT)^{24}Na$	2754.028	1.33E-05
5	Ca	286	$^{48}Ca(n,2n)^{57}Ca(b-)^{47}Sc$	159.381	4.08E+00
5	Fe	2400	$^{54}Fe(n,a)^{51}Cr$	320.082	2.54E+02
5	Na	12600	$^{23}Na(n,2n)^{22}Na$	1274.53	2.92E+01
5	Zn	13	$^{66}Zn(n,2n)^{65}Zn$(99.76%)+ $^{64}Zn(n,g)^{65}Zn$(0.24%)	1115.539	1.69E+00

Results

Simulated Spectra Examples

Tirr=6.5 h, Tcool=31 min, Tmeas=24 h





Observed peaks

Verification Experiment

- 5.5MV Van de Graaff Tandem Accelerator of N.C.S.R. "Demokritos" in Athens. Neutrons production: $^{3}\mathrm{H}(^{2}\mathrm{H},\mathrm{n})^{4}\mathrm{He}$, $\mathrm{E_d} = 3.45\ \mathrm{MeV}$ and $\mathrm{E_n} = 18.9\ \mathrm{MeV}$
- IAEA A-13 and IAEA Soil 7 samples irradiated $(t_{irr} = 6.5\ h)$ (Fig. 1) and measured by a HPGe detector of 80% relative efficiency and a Ge detector of 40% relative efficiency respectively

Figure 1: (a) samples irradiated, (b) irradiation system,(c) Ge detector (d) HPGe detector

However, technical difficulties did not allow to achieve the required neutron fluence and obtain meaningful gamma spectra

Concluding Remarks

The potential of NCSRD tandem accelerator neutron beams for FNAA were investigated using the NAAPRO code

Samples representing geological and biological materials were examined.

The results of the study showed that in Soil-7 (Si, Ca, Cd, As, Ni, Sb) and in A-13 (P, K, Fe, Mg, Ca, Na, Zn) can be determined above MDLs

Great interest in environmental and trace element in biological samples studies

Future Work

- Technical difficulties at the accelerator did not allow us to experimentally validate these results, which will be the aim of a future study now planned
- Study of other neutron energies to take advantage of nuclear reactions with different energy thresholds
- Comparison of the NAAPRO code with other equivalent computational codes, such as FISPACT-II and Neutron Activation Analysis DataBase (NAADB)