Neutron activation to determine degree of ^{76}Ge enrichment

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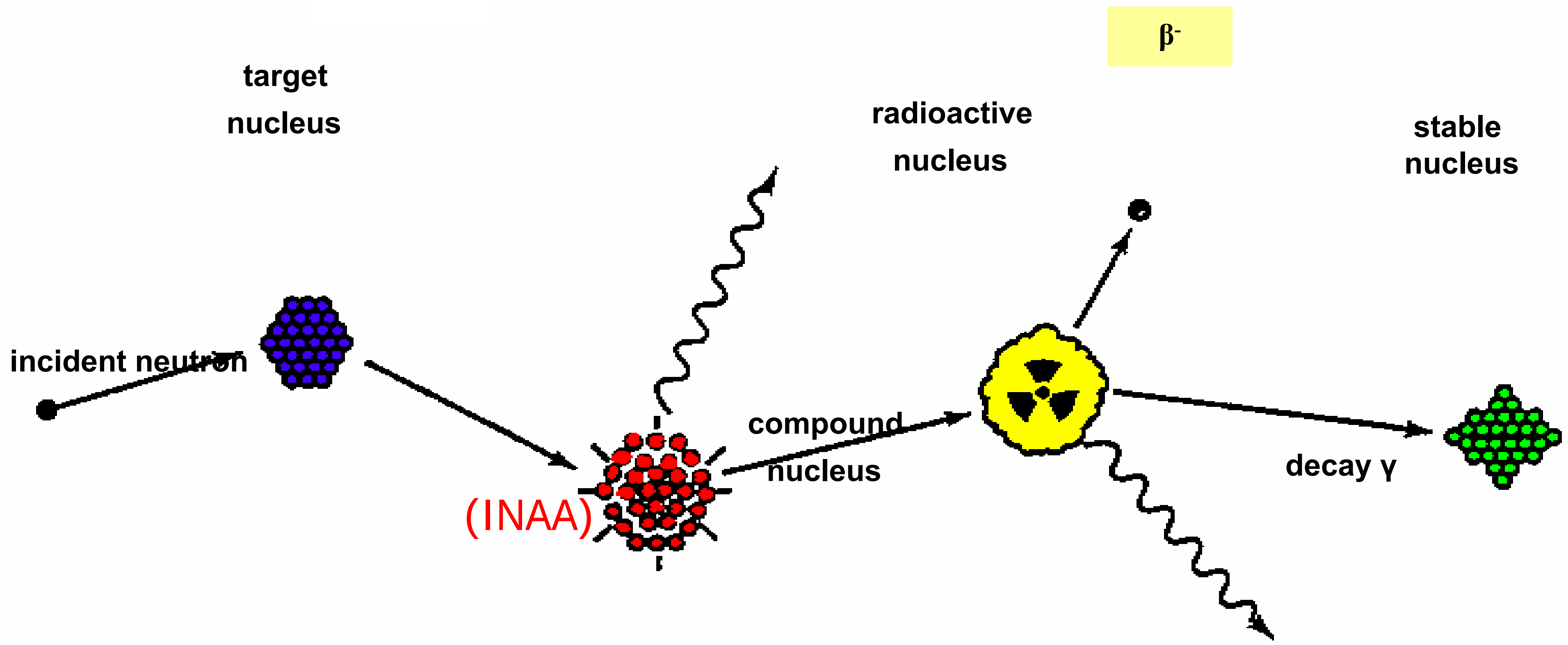
NAA – The principle

- Incident neutron collides with the target nucleus;
- Compound nucleus forms, very high activity;
- Compound nucleus settles into a less active state (decay);
- Gives off radiation, specific to its element.



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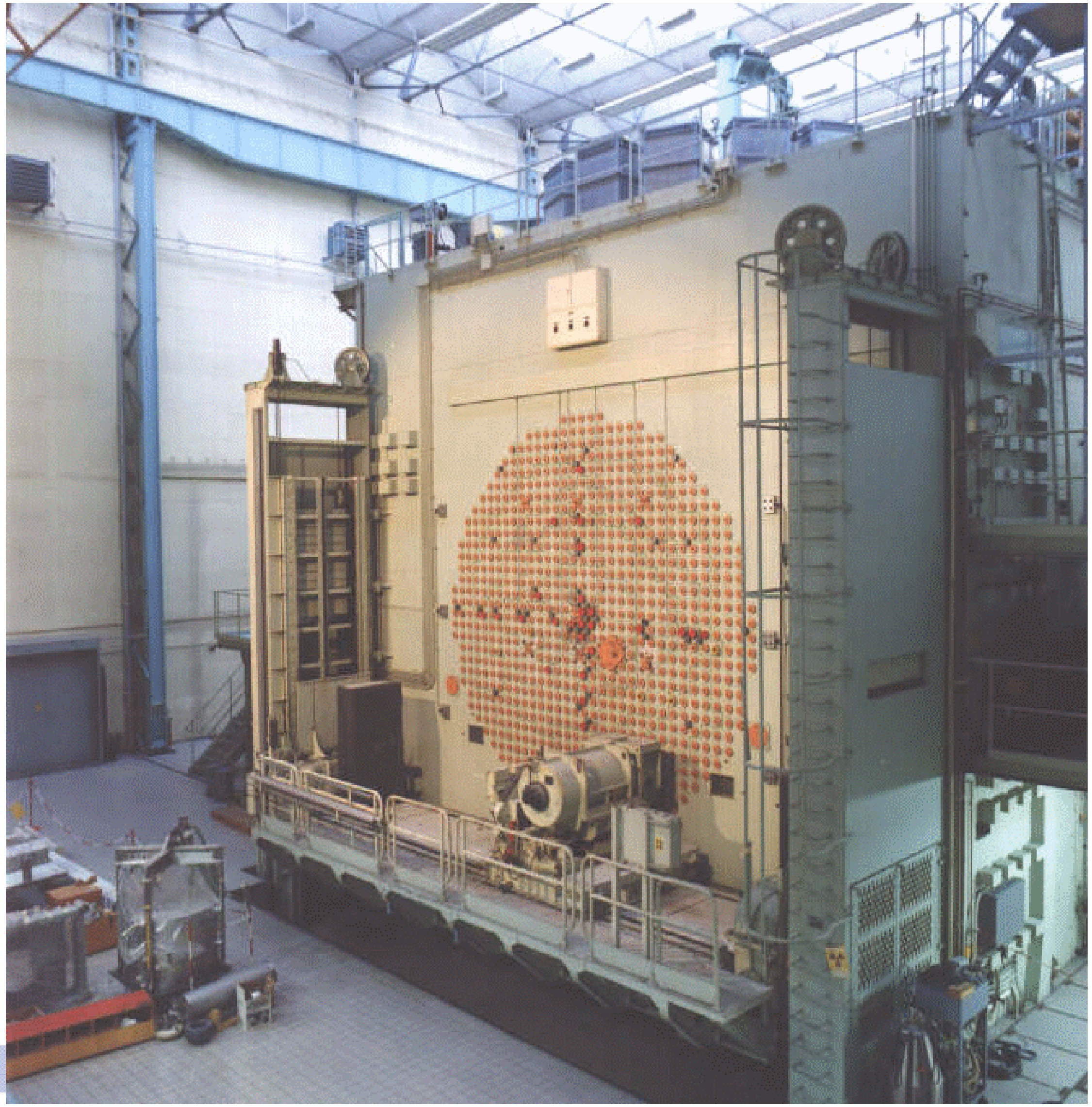
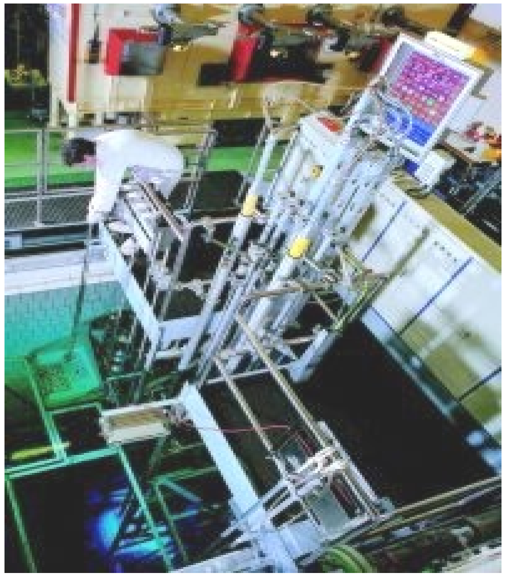
Belgian Reactor 1 (BR1) Low flux, but very stable and well characterised





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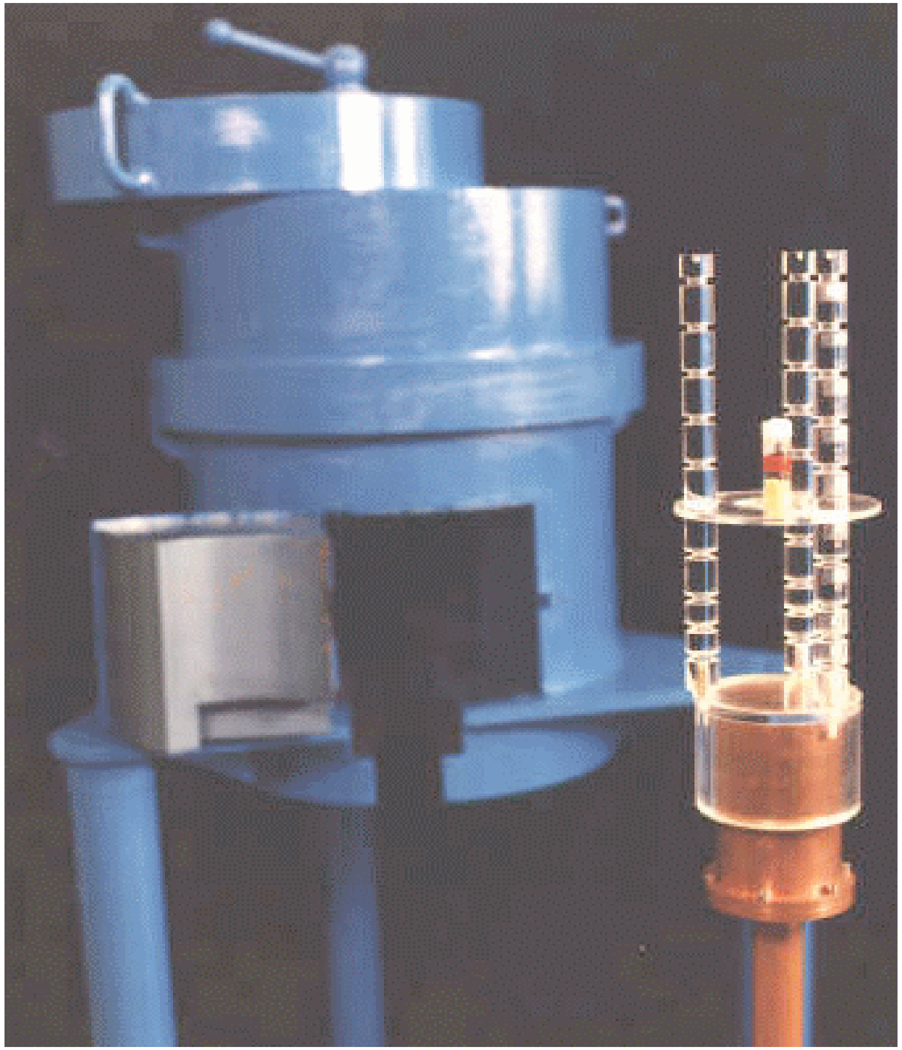
Facilities: 2. HPGe γ-ray spectrometer



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INAA – GeO_2 (enriched)

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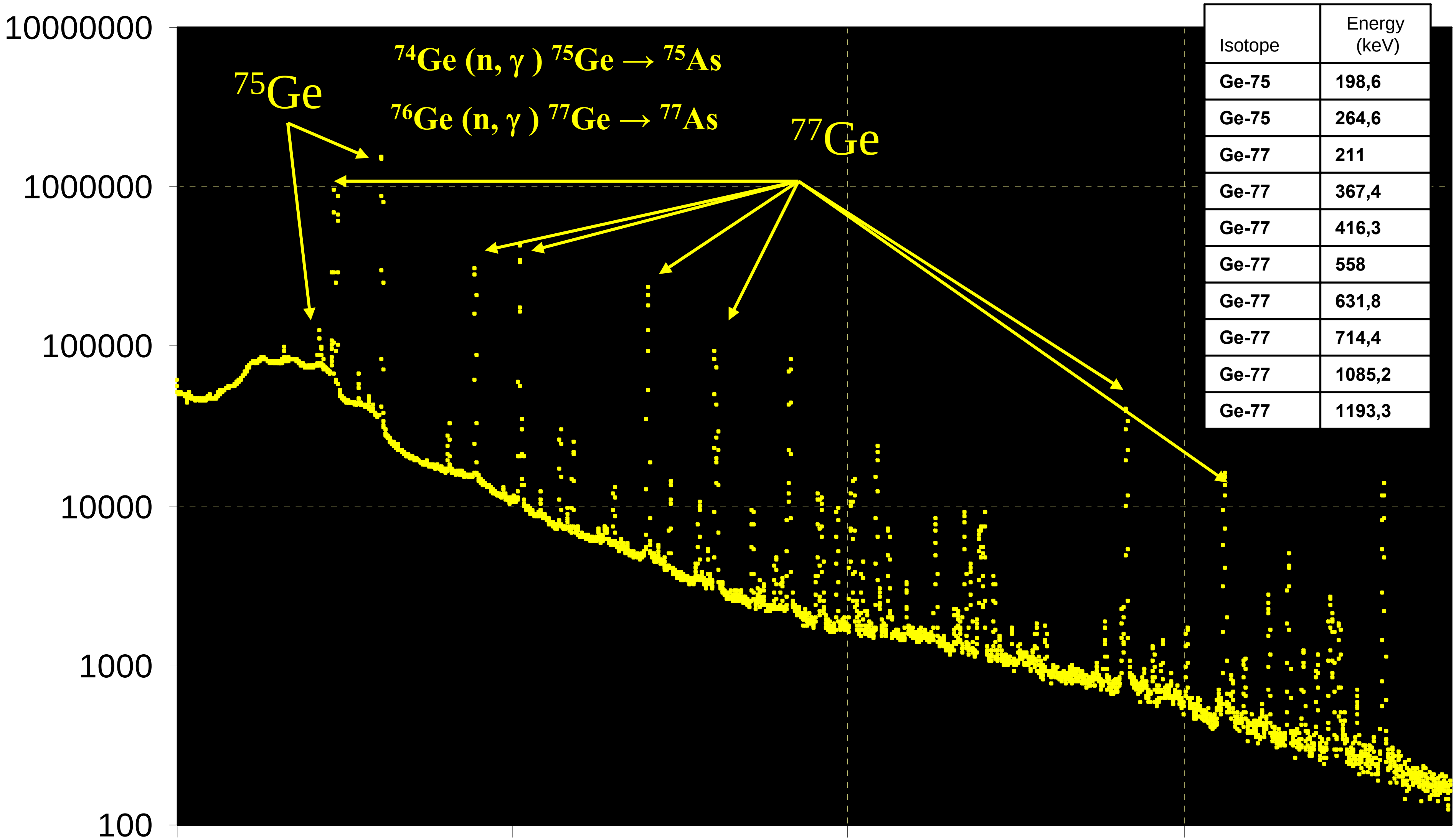

Isotope	Energy (keV)
Ge-75	198,6
Ge-75	264,6
Ge-77	211
Ge-77	367,4
Ge-77	416,3
Ge-77	558
Ge-77	631,8
Ge-77	714,4
Ge-77	1085,2
Ge-77	1193,3

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SCK: k0-INAA standardization

- **Absolute method: completely determined by the physical parameters of the irradiation and the measurement (Ge-detector, measurement container, …) – but k_0-values for Ge are not very well characterized**
- **Therefore: reference method versus natural GeO_2**

The pro's

- Complementary to most chemical techniques because the fundamentals and the processes are completely different
- Largely matrix independent;
- Large dynamical range from ppb to several % and this for samples from a few mg – so in the same run trace elements could be determined
- The sample is analysed in bulk, so there is no sample preparation or the sample needs not to be dissolved (so good for powders, solid material, plastics, …)
- "Non-destructive" (Ge-sample was given back after a few weeks)
- But, … no results in a day

Calculation-1

$$C = T_{irr} T_{dec} T_{meas} N_{76Ge} \varepsilon P_{\gamma} \Phi \sigma$$

$$N_{76Ge} = \frac{m \theta N_{Avo}}{M}$$

Calculation-2

$$\theta = \theta^{std} \frac{C}{C^{std}} \frac{M}{M^{std}} \frac{m^{std}}{m} \frac{T_{dec}^{std}}{T_{dec}} \frac{T_{meas}^{std}}{T_{meas}}$$

Assuming: ^{70}Ge: 0%, ^{72}Ge: 0.03%, ^{73}Ge: 0.13%

To calculate M.

Iterative procedure that converged very quickly.

Low uncertainties in all parameters

(0.5% in LFC, 0.7% overall)

Results -1

	SCK (NAA)		From centrifuges		LNGS (ICP-MS)	
Batch	^{74}Ge (%)	^{76}Ge (%)	^{74}Ge (%)	^{76}Ge (%)	^{74}Ge (%)	^{76}Ge (%)
1711	12.5±0.3	87.1±1.2				
1714	12.1±0.3	86.9±1.2				

k=2 (95% coverage factor)

Assuming: ^{70}Ge: 0%, ^{72}Ge: 0.03%, ^{73}Ge: 0.13%

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Results -2

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Trace elements

Fe: 6 mg/kg

Co: 6 mg/kg

Zn: 2.2 mg/kg

Se: 0.2 mg/kg

Sb: 40 mg/kg

Ce: 130 mg/kg

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Various measurement info

- Half-life ^{75}Ge ~ 1h
- Half-life ^{77}Ge ~ 4h
- Low statistical uncertainty due to use of many (^{75}Ge: 2, ^{77}Ge: 8) gamma-lines (same results from all of them)
- Two sub-samples were used => in total: 4 enriched samples and 2 of normal isotopic abundance
- m ~ 0.8 g
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