THICK TARGET EXPERIMENTS AND MONTE CARLO CALCULATIONS FOR PLANETARY GAMMA RAY SPECTROSCOPY;

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With Thick Target experiments basic features of the remote sensing method 'Planetary Gamma-Ray Spectroscopy' were simulated at an accelerator. Basalt and iron targets of different compositions were irradiated with energetic protons and gamma-ray spectra were measured, simultaneously. To evaluate the analytical technique, the geometry of the experimental setup was modeled and the gamma ray fluxes were calculated by using Monte Carlo transport codes. The comparison of measured gamma-ray fluxes with Monte Carlo calculated values shows, that most of the prominent gamma-ray lines can be reproduced in Monte Carlo calculations within 10%.

A planetary body is permanently bombarded by galactic cosmic rays. If there is no thick atmosphere and strong magnetic field, secondary gamma rays are emitted by the planetary surface. By measuring these gamma rays on board an orbiting spacecraft or a lander on the surface, the chemical composition of the surface can be determined. To evaluate the method of planetary gamma-ray spectroscopy, accelerator experiments were carried out. The galactic cosmic ray (GCR) bombardment of a planetary surface was simulated by irradiating a large piece of matter (Thick Target) with a energetic proton beam. The emitted gamma rays were recorded by a high resolution germanium gamma-ray detector in front of the target corresponding to a detector on board an orbiting spacecraft. The major differences to the 'real world' were a pencil shaped, monoenergetic proton beam instead of the GCR energy spectrum with a 2π irradiation and a finite Thick Target with different components instead of a an infinite planetary surface [1].

Elem.	Target 1 [wt.%]	Target 2 [wt.%]	Target 3 [wt.%]	Target 4 [wt.%]
H	0.42		0.72	0.44
C			2.26	0.64
O	39.8		40.0	40.8
Na	1.68		1.77	1.81
Mg	4.34		6.06	6.19
Al	8.38		6.38	6.51
Si	19.3		19.1	19.6
P	0.22		0.26	0.27
S			2.39	2.33
Cl			0.74	0.72
K	1.19		1.17	1.19
Ca	6.28		7.05	7.20
Ti	1.29		1.53	1.56
Mn	0.16	0.44	0.13	0.13
Fe	16.8	99.0	8.14	8.31

Table 1: Compositions of the Thick Targets

Each of the Thick Targets consisted of three parts: a surface target for the gamma-ray emission, an inner core to stop the primary proton beam, and an iron sleeve to confine secondary particles. The total size was $1.8 \cdot 1.6 \cdot 1.5\ m^3$. Since the gamma rays that can be measured outside the target, originate mainly from an upper layer, four surface targets of 40 cm thickness could be used: target 1 contained basalt blocks with iron inserts; target 2 was made of pure iron; target 3 and 4 consisted of similar basalt blocks as target 1, of thin PVC inserts (chlorine, hydrogen, and carbon), and of sulfur sheets; target 3 contained additional sheets of polyethylene plastic simulating a high water content. For all basalt targets, an inner core of pure basalt was used, for the iron target an inner core of iron. Details of the experimental setup are described in [2].

During the pulsed proton irradiations of the Thick Targets, several kinds of gamma-ray spectra were recorded: (1) total gamma-ray spectra (i.e. prompt and delayed radiation) emitted by the target and the surrounding material (e.g. experimental hall); (2) spectra of delayed radiation emitted by target and surroundings; (3) total spectra emitted by the surroundings only, with a movable lead shield between target and gamma-ray spectrometer; (4) delayed spectra from the surroundings. The gamma-ray fluxes incident at the detector were calculated from the measured peak areas in the spectra, the detector peak efficiencies, and the dead time corrected proton count rates. The prompt gamma-ray fluxes originating from the Thick Target were determined by subtracting the total gamma-ray contribution of the surrounding material and the delayed gamma-ray radiation from the total flux. The gamma-ray fluxes are given in photons per cm^2 and per incident proton on the target, as done in the Monte Carlo calculations.

In the spectra of the water free Target 2, gamma-ray lines from neutron scattering reactions dominate, while neutron capture lines dominate in the three basalt targets, whose hydrogen content corresponds to 3.8%, 6.5%, and 4.0% of water for the Targets 1, 3, and 4, respectively. In general, the increased hydrogen content caused lower gamma-ray fluxes, for scattering lines more than for capture lines, as expected.

In normal chemical analysis, an unknown sample is compared with one or several standards. In planetary gamma-ray spectroscopy, this approach is not feasible, since no standards are available on an unknown planetary surface. Therefore, simulation calculations of the gamma-ray production and emission have to prove that they can serve as a kind of standard. The exact experimental setup was modeled and gamma ray fluxes were calculated by

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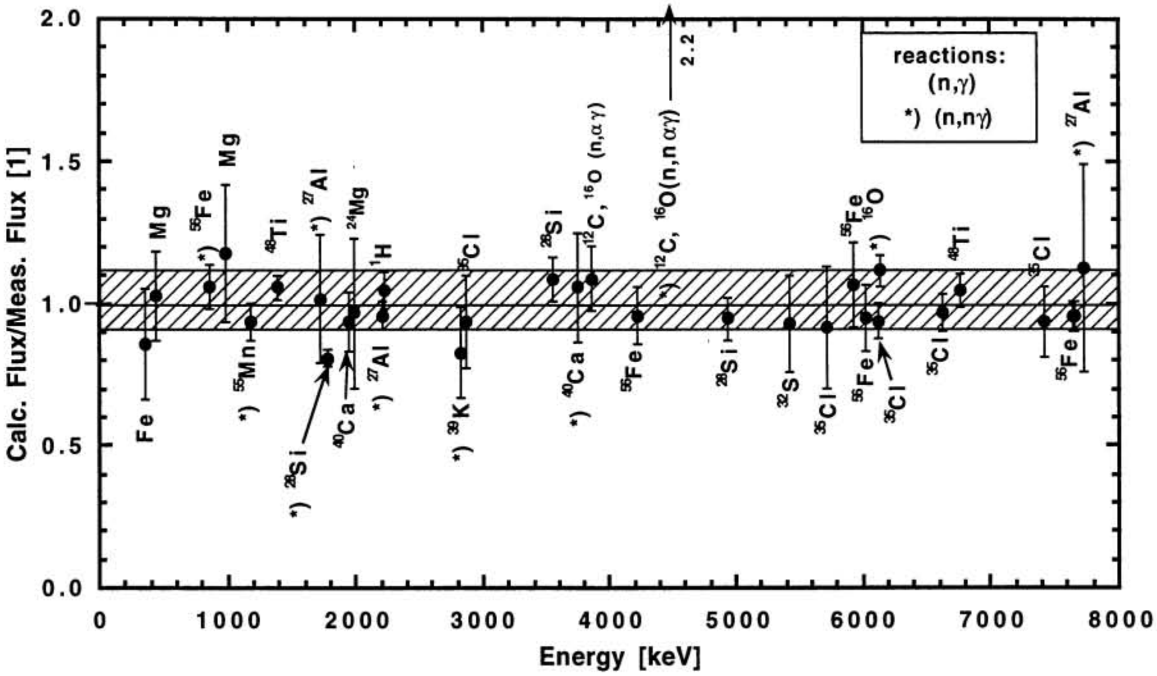

Figure 1: Ratios of calculated to measured gamma-ray fluxes for selected, prominent lines of Target 4, at least one (n,γ) and (n,nγ) line per isotope, if possible. Error bars show the propagated errors from measured peak areas and their correction terms.

using high-energy particle transport codes. These calculations are based on the Los Alamos LAHET Code System (LCS) [4]. This is a system of general-purpose, continuous-energy, generalized-geometry, time-dependent, off-line coupled Monte Carlo computer codes that treat the relevant physical processes of particle production and transport. This code system and its application to planetary problems is discussed in more details in [5]. While LCS can calculate gamma-ray line fluxes, we used this option only for rates of neutron-capture reactions, where the MCNP code is coupled to massive libraries that contain state-of-the-art neutron capture cross sections. In all other cases we used LCS only to calculate the fluxes of neutrons that lead to gamma-ray production. The actual inelastic gamma-ray production was determined off line by using special inelastic cross section libraries. These gamma-ray fluxes, transported to the detector position, are directly comparable to the experimentally derived incident gamma-ray fluxes. The ratios of calculated to measured gamma-ray fluxes of the unambiguously identified lines are depicted in Figure 1. These ratios show deviations of about ten percent from unity for most of the prominent gamma-ray lines. The other targets revealed similar good results.

However, the measured gamma-ray fluxes of some inelastic reactions, such as ^{12}C (n,nγ) and ^{27}Al (n,nγ), could not be well reproduced by the LCS calculations. The gamma-ray peaks of these two reactions show peculiar shapes as a result of Doppler broadening. The carbon peak shows a symmetrical broadening compared to the width of normal peaks, while the Al line has a high energy tailing. The poor match of calculated to measured data may result from either difficult peak area deconvolutions or from erroneous inelastic neutron cross sections. Further investigations may be recommended, especially since carbon is a major constituent of comets.

The comparisons of calculated and measured gamma-ray fluxes prove, that the analytical procedure provides accurate information on concentrations of all major and some minor rock forming elements. Being aware of the complexity of the performed experiments and calculations, the quality of the final matching is a major milestone.

References:

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