Applications

- **Spectroscopy**
  classical "complete" spectroscopy of the decay of excited nuclear states

- **Lifetimes**
  measurement of lifetimes of excited nuclear states (by gamma-ray induced Doppler broadening - GRID)

- **Standards**
  measurement of fundamental constants
  measurement of standards for x-rays and gamma-rays

- **Crystal Diffraction**
  detailed studies of crystal diffraction processes

- **Interatomic Potentials**
  study of slowing down processes of atoms recoiling in matter

Selected examples

**Lifetime spectroscopy**

Nuclei display many diverse modes of excitation. It is sometimes possible to interpret the behaviour of the nuclear system in terms of the motion of individual particles while in other cases it shows correlated collective behaviour such as rotations or vibrations of the nucleus as a whole or the movement of surface waves around it. As a consequence different models are needed to describe the many features observed in nuclei. The interplay between the different degrees of freedom in a nucleus can be studied by investigating the processes of either its excitation or de-excitation. These can be effectively characterized via the measurement of the gamma transitions involved. The most crucial information is thereby obtained from absolute transition rates which are related to the knowledge of the state lifetimes. The probability for the decay of an excited nuclear state is proportional to the square of the matrix element of the transition operator between the initial and final state wave function. Therefore, measured lifetimes provide a sensitive test of the validity of different theoretical approaches. The GRID method can be applied to all nuclei which can be reached by thermal neutron capture. In exceptional cases nuclei with up to 2 neutrons beyond stability have been studied. Due to the extreme resolving power natural target materials can be used. Examples for lifetime studies concern for instance the observation of mixed symmetry states in $^{52}$Cr, the investigation of multiphonon excitations in medium heavy nuclei like $^{114}$Cd, the determination of quadrupole-octupole coupled states in $^{168}$Er and the search for multiphonon excitations in heavily deformed nuclei like $^{144}$Nd. The main difficulty of the method concerns the often sparsely known feeding of a given level (needed to describe the initial recoil velocities). This can be overcome by simulating it with statistical models or by extracting upper and lower lifetime limits which depend on extreme feeding assumptions about the population routes and intensities.

**Precision Measurement of the $^{29}$Si, $^{35}$S, and $^{35}$Cl Binding Energies**

The binding energies of $^{29}$Si, $^{35}$S, and $^{35}$Cl have been measured with a relative uncertainty $< 0.65 \times 10^{-3}$ using the GAMS4 flat-crystal spectrometer. The unique features of these measurements are 1) nearly perfect crystals whose lattice spacing is known in meters, 2) a highly precise angle scale that is derived from first principles, and 3) a gamma-ray measurement facility that is coupled to a high flux reactor with near-core source capability. The binding energy is obtained by measuring all gamma-rays in a cascade scheme connecting the capture and ground states. The measurements require the extension of precision flat-crystal diffraction techniques to the 5 to 6 MeV energy region, a significant precision measurement challenge. The measured binding energies have an uncertainty that is significantly less (factors of 7, 67, and 16 for $^{29}$Si, $^{35}$S, and $^{35}$Cl respectively) than the uncertainty that is associated with binding energies determined from atomic mass tables.

**Slowing down of atoms in metals studied by the Doppler-broadened gamma-ray line shape**

Molecular-dynamics simulations describing the slowing down of atoms in solids are used to study interatomic potentials in metals. This analysis is achieved by observing the fine structures of Doppler-broadened gamma-rays emitted by recoiling excited nuclei. The recoil of the atom, $\sim 400$ eV kinetic energy, is generated by the emission of a preceding gamma-ray following thermal-neutron capture. The experiment was performed with oriented single crystals of Fe and Cr as target and high-resolution gamma-ray spectroscopy. Two different nuclear levels for each element were studied and the best interatomic potential among many available in the literature could be deduced from the data. The construction of a different potential was also investigated with this technique. Lifetime values with a much improved precision were obtained for four excited nuclear levels.
The high resolution gamma ray facility GAMS makes use of the fact that at the ILL reactor one can obtain extremely high specific activities when exploiting thermal neutron capture at an in-pile target facility. This allows us to aim for the application of gamma spectroscopy with the highest possible energy resolution. Many studies on this facility have aimed to contribute to our understanding of the structure of nuclei. Others are devoted to the determination of standards and fundamental constants or to deduce information about short lifetimes of excited nuclear states.

**Instrument description**

**Gamma-Ray Spectrometers GAMS 4 and GAMS 5**

The ultra high resolution gamma ray spectrometers GAMS 4 and GAMS 5 are crystal spectrometers working in Laue geometry. The basic concept of these instruments is to provide the best possible energy resolution by diffraction of gamma rays from perfect crystals, according to Bragg’s law. Both can operate with flat, nearly perfect Si or Ge crystals. In addition, a doubly bent crystal mode for GAMS 5 is also available.

High angular resolution is obtained by using high precision optical interferometers. For this purpose the spectrometer crystals are mounted on interferometer arms. These can be rotated using a combined step motor/piezo device. Angular steps as small as 0.0004 arcsec are possible.

With GAMS 4 extremely precise absolute measurements of gamma-etalons are made possible by an in-situ angle calibration of the interferometer.

**References:**

**Instrument layout**

**Instrument Data**

<table>
<thead>
<tr>
<th>Reactor hall, through-tube H6-H7</th>
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<tbody>
<tr>
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**Detector** Flat crystals Collimator Sample changer H$_2$O D$_2$O Fuel element Collimators Soller collimator Detector Spectrometer table Trolley