LA-UR 02-6125

LANSCE

Los Alamos
NATIONAL LABORATORY

(n, γ)-measurements on radioactive isotopes

René Reifarth

1. Workshop of the Joint Institute for Nuclear Astrophysics,
Gull Lake, Michigan, October 6 - 8, 2002

This paper should be understood as an extended version of a talk given at the

1st JINA workshop at Gull Lake, 2002.

Abstract:

Recent experimental developments at LANL (Los Alamos, NM, USA) and CERN (Geneva, Switzerland), which are scheduled to be operating in the next future, will offer the possibility of measuring neutron capture cross sections of radioactive isotopes at stellar neutron energies close to the valley of stability. These information will fill crucial gaps in the experimental nuclear databases, needed for a precise understanding of the s-process. An accurate understanding of the s-process nucleosynthesis is the key for determining the solar r-process abundance, hence necessary for understanding the r-process nucleosynthesis.
Furthermore the planned experiments might offer possibilities of measuring neutron capture cross sections of radioactive isotopes even further away from the valley of stability, hence closer to the r-process path.
During the talk the present status of (n,γ)-experiments will be presented and ideas for possible future experiments will be discussed.

Problems

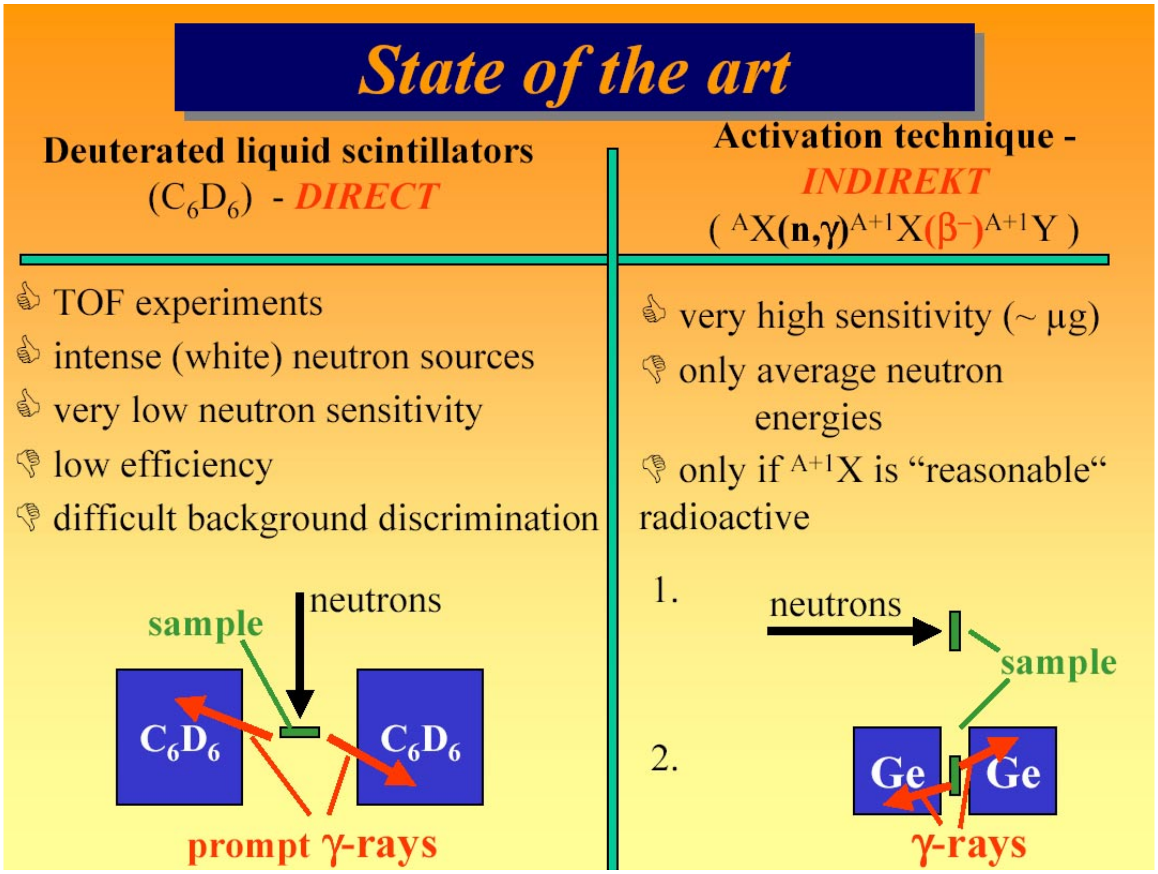
- very ***small samples*** (~ mg)
- low ***count rate***
- neutron reactions with sample ***backing***
- ***radioactivity*** of the sample
- sample-independent background

Measurements on radioactive isotopes have to face different new problems compared to measurements on stable isotopes.

Because of the radioactivity, usually the material needs to be produced using accelerator facilities or reactors rather than found on earth. Further more the total amount of radioactive material is strictly limited by safety regulations. Both together mean, that the sample mass is usually limited well below 1 g. Therefore only small count rates are expected.

Because of the small sample masses additional sample backing is required in order to provide mechanical stability. Depending on the isotope, the mass of the backing can exceed multiples of the sample itself.

The most general attempt of measuring (n,γ) cross section is to detect the prompt γ-rays following a neutron capture event. Many detection systems used for (n,γ)-measurements can not disentangle between capture γ-rays and γ-rays emitted after a radioactive decay. Therefore the radioactivity of the sample itself is a challenging background component.



So far two different attempts are made in measuring neutron capture cross sections on radioactive isotopes:

TOF experiments using liquid scintillators: White neutron sources provide neutrons from thermal energies up to hundreds of MeV. Neutrons arrive at the sample after a certain flight path. Capture events resulting in prompt γ-rays are detected with liquid scintillator detectors, optimized for low neutron sensitivity. These detectors can not disentangle between signal and different background components because of their very poor efficiency and energy resolution.

Activation technique: If the reaction product of a neutron capture is again radioactive, the activation technique can be applied. The produced activity will be taken as evidence for a (n,γ)-reaction. Taking advantage of (p,n)-reactions close to the threshold allows to produce neutrons with energy distributions similar to the stellar nucleosynthesis site. The induced additional activity can be measured with high efficiency Ge-detectors allowing to discriminate the radioactivity of the sample material and other background components. The sensitivity of this technique is very high, samples below 1 µg can be analyzed.

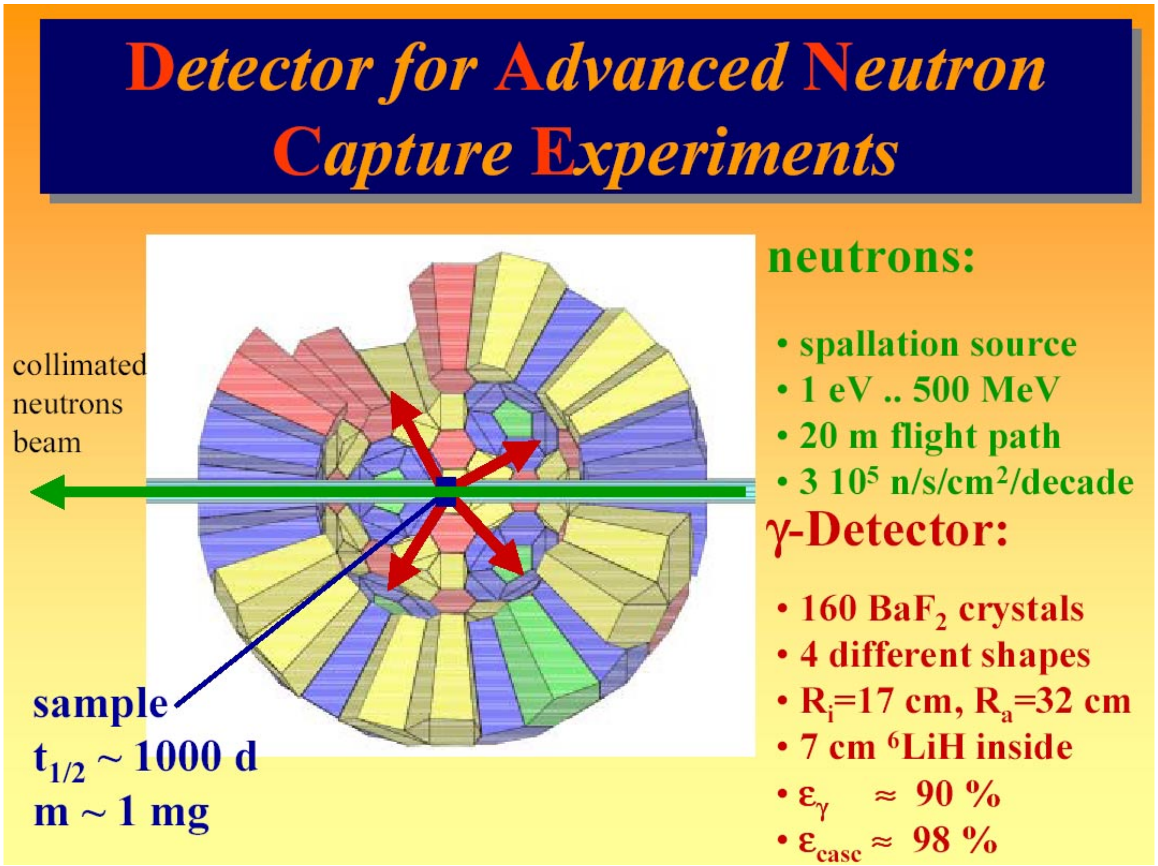
Evidence for neutron capture: DIRECT

$^{A}X + n \Rightarrow {}^{A+1}X + \mathbf{Q}$

$$Q = \sum \gamma_i$$

⇨ "monoenergetic" if 100 % efficiency

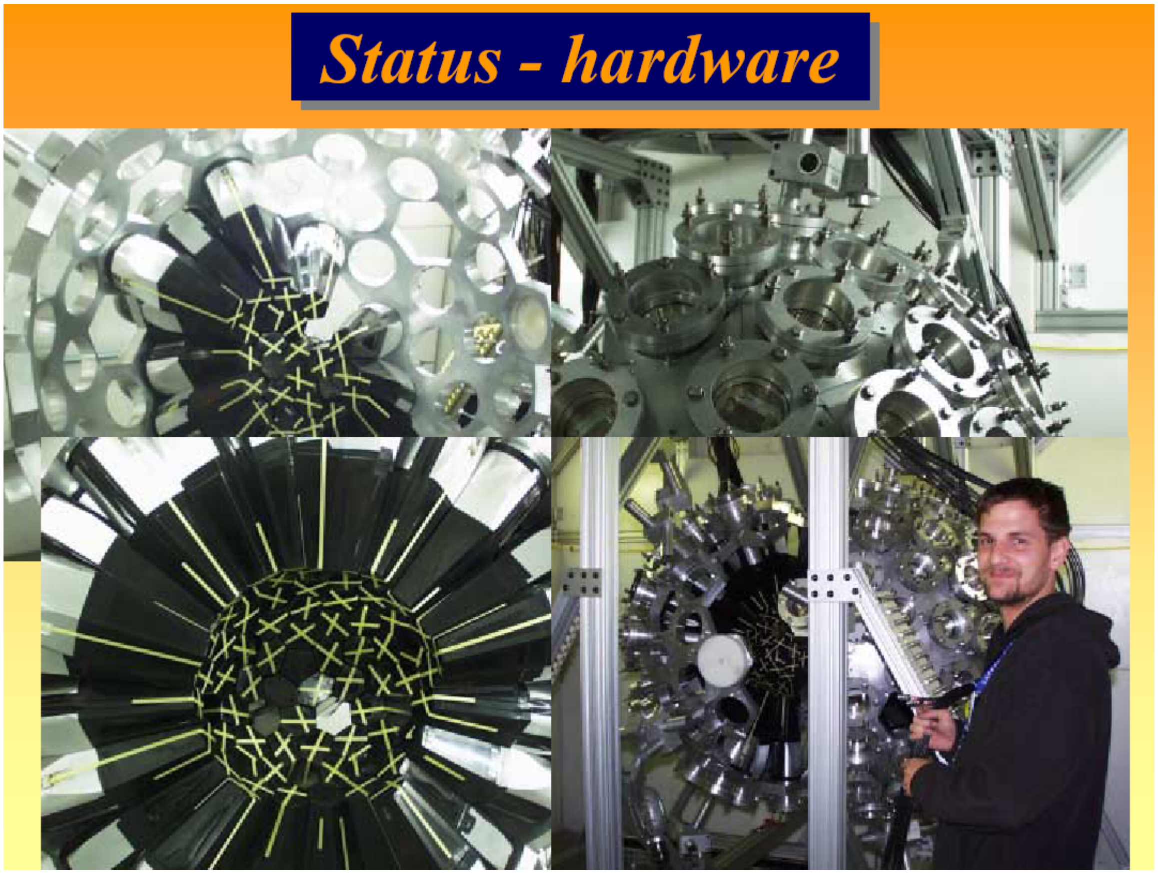
A neutron capture leaves the nucleus in a very excited state. During the deexcitation statistically determined γ-cascades are emitted. The only information, uniquely related to the isotope that captured the neutron, is the total energy emitted during the process. Therefore a 100 % efficiency γ-ray detector would allow to disentangle between neutron captures on the sample material and captures of the unavoidable scattered neutrons in the surrounding material.



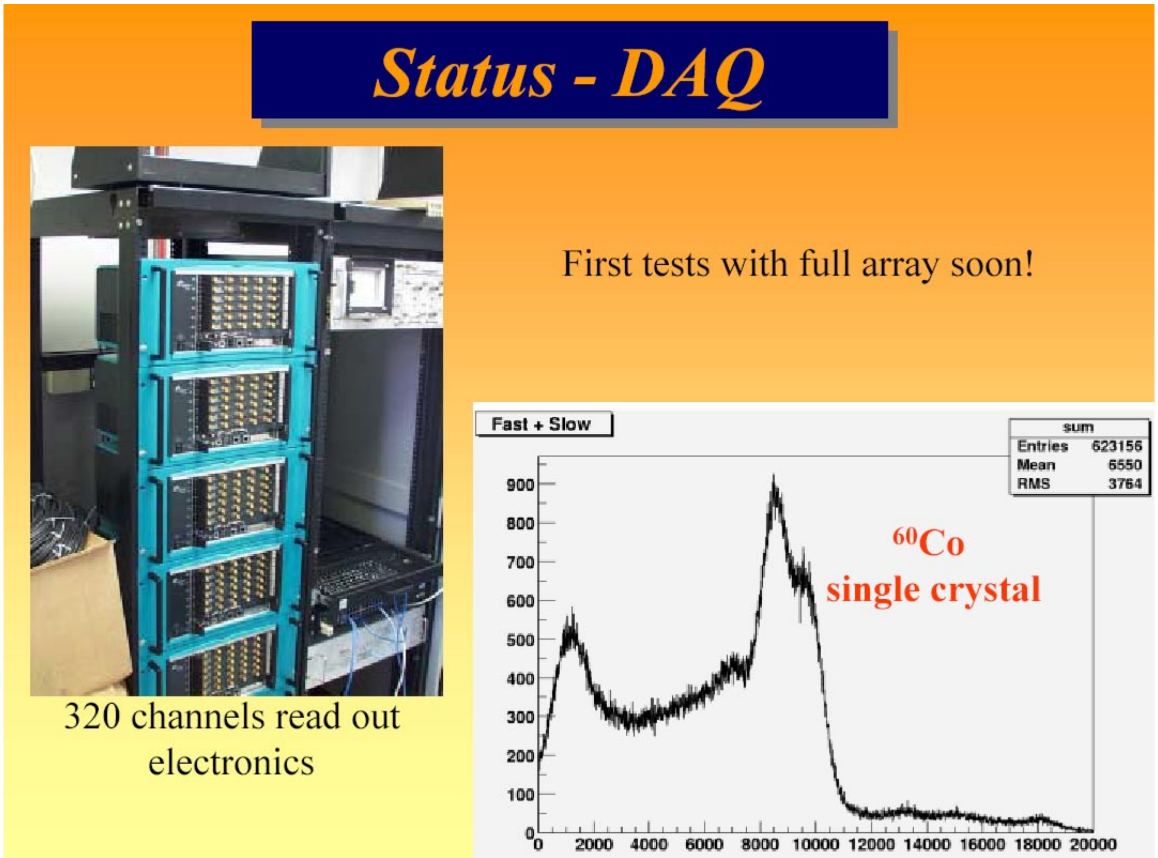
The Detector for Advanced Neutron Capture Experiments (DANCE) at the Los Alamos Neutron Science (LANSCE) facility at the Los Alamos National Laboratories (LANL) is designed to measure neutron capture cross sections of radioactive nuclei. About 1 mg sample mass is sufficient for a successful measurement, corresponding to a minimum half life of a few years.

The detector consists of 159 BaF_2 crystals (162 would form a closed sphere) of 15 cm length and has a total efficiency for MeV-γ-rays of about 90%. This results in a detection probability for cascades of 98 %. The ball leaves an inner sphere of 17 cm radius, which will be partly filled with a ^{6}LiH neutron absorber.

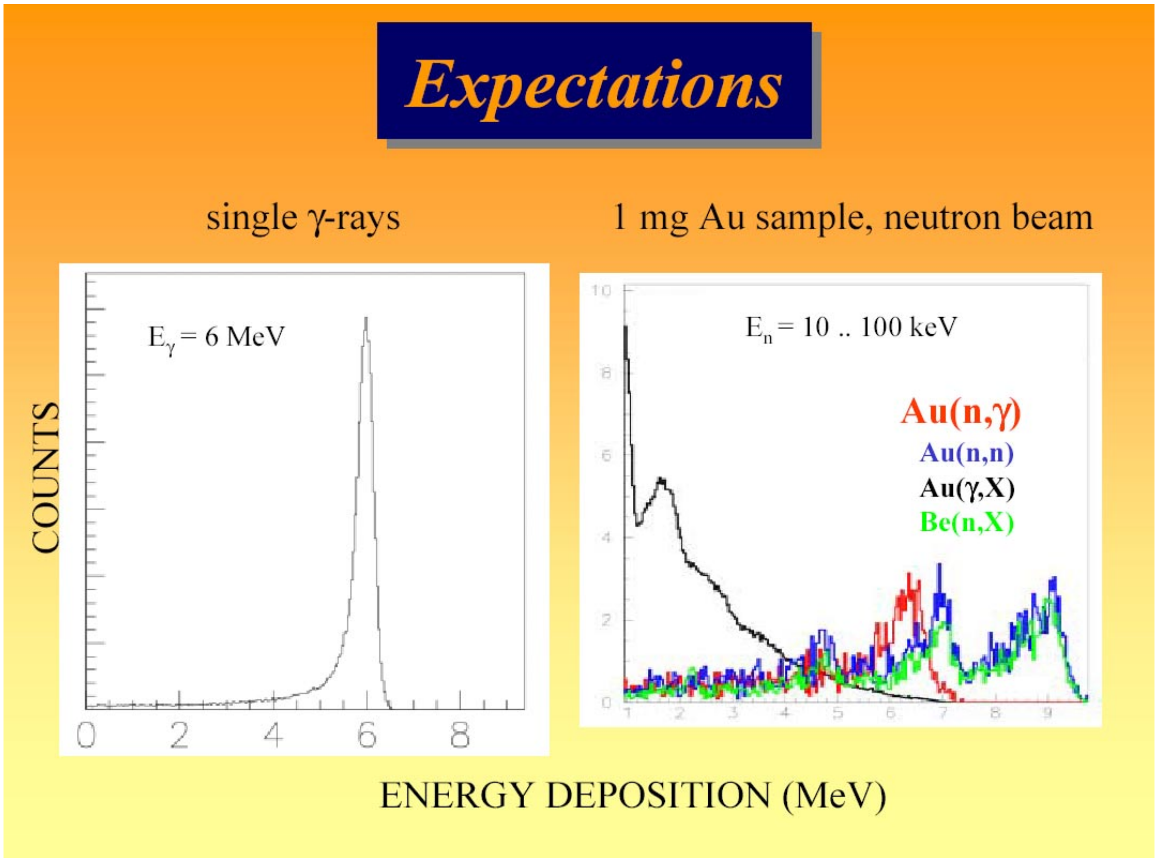
The LANSCE spallation neutron source is able to provide 3 10^5 n / s / energy decade at a flight path of 20 m.



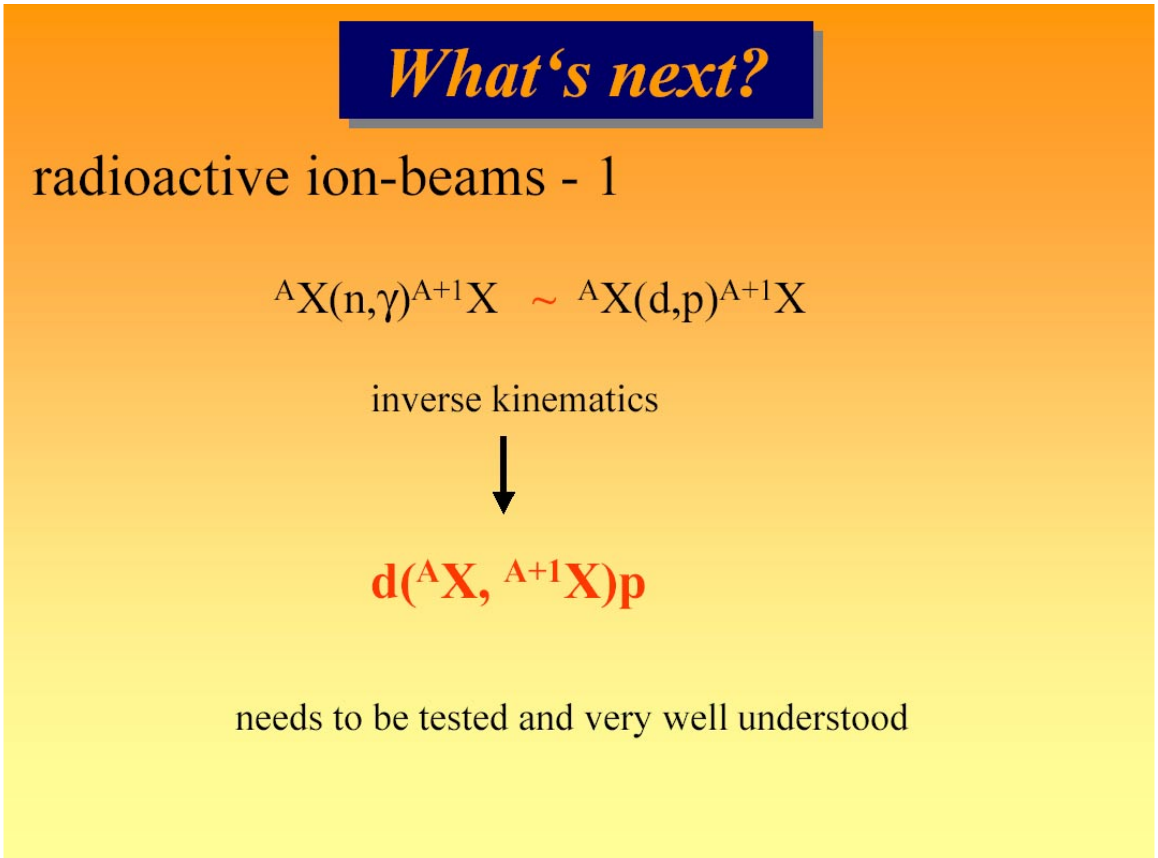
The DANCE detector is scheduled to be operational at the end of 2002. The pictures above are taken during the mounting process of the detector modules in summer 2002.



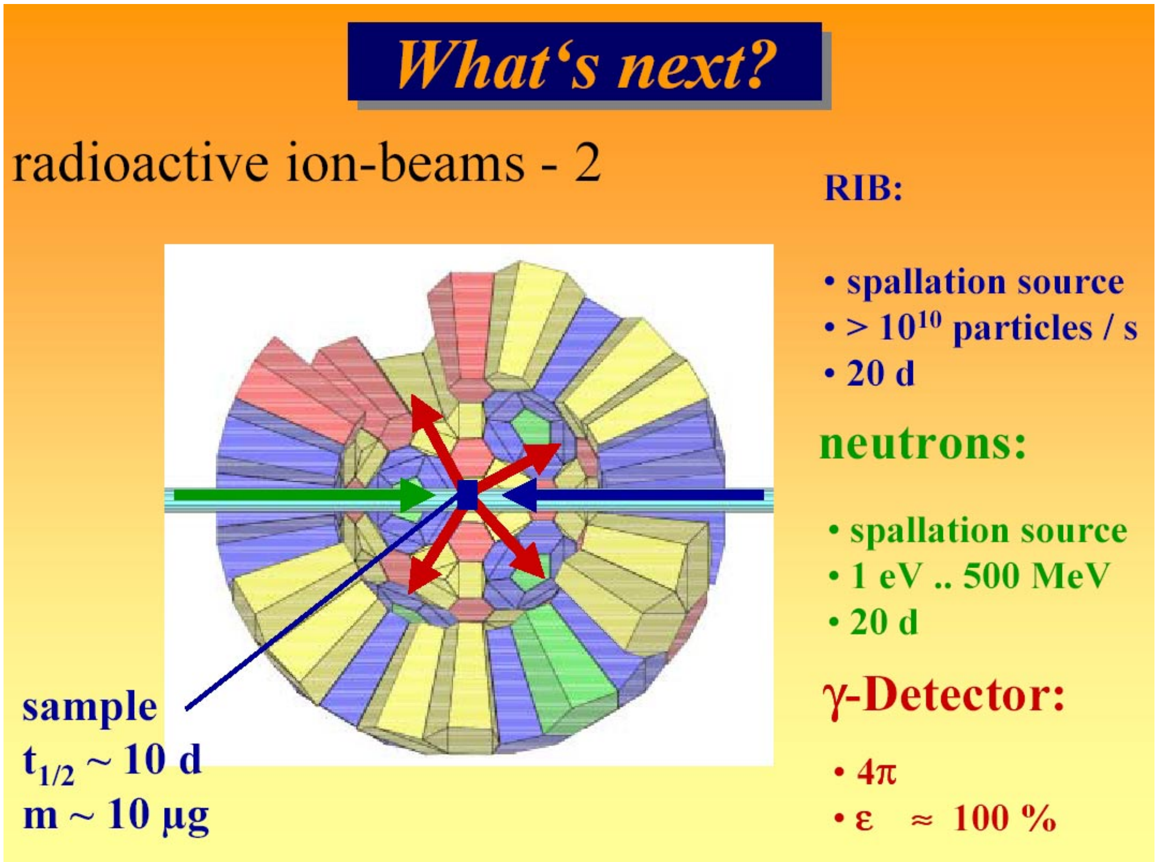
In order to take full advantage of the fast timing, the good energy resolution and the high repetition rate at LANSCE, sophisticated data acquisition is needed. 320 channels flash ADC are planned to read out the 160 crystals of the DANCE array. The spectrum in the picture above shows the result of a run with a ^{60}Co calibration source for a single crystal.



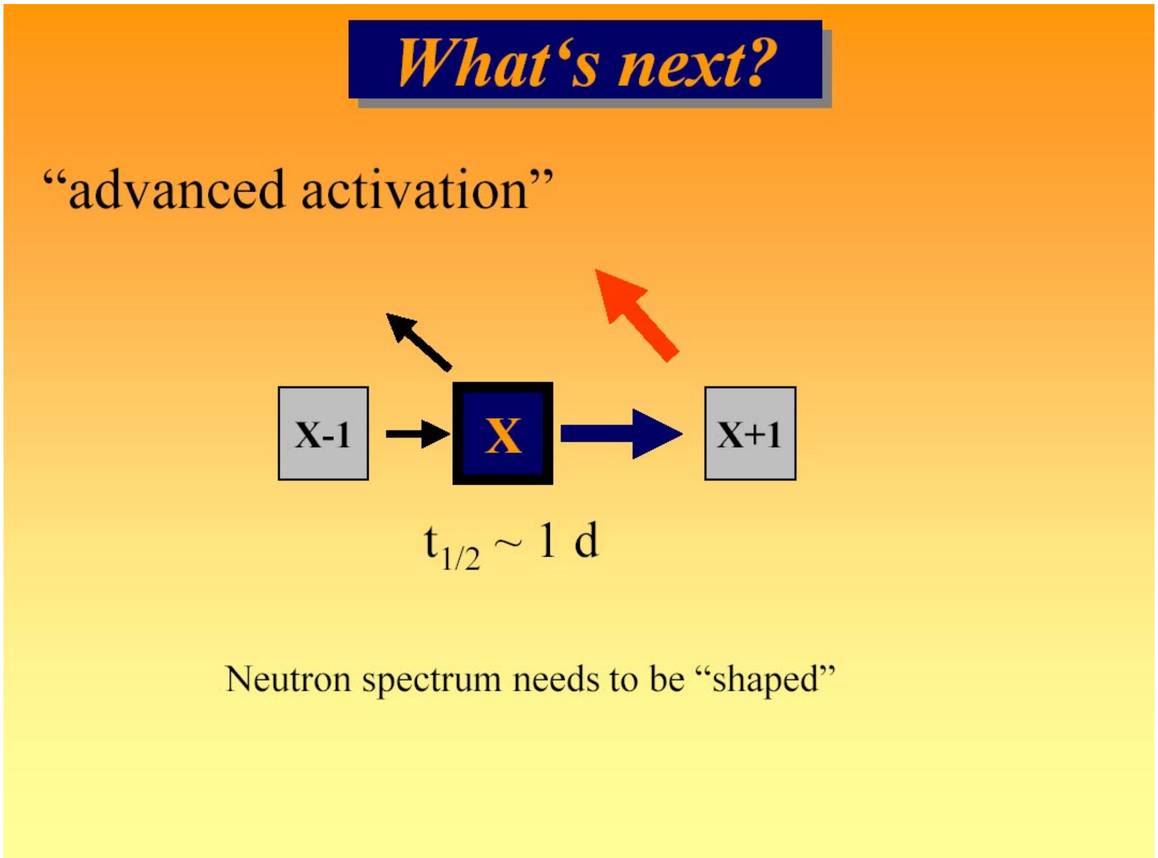
In order to understand the rather complex DANCE array, many detailed GEANT simulations have been carried out, accompanying the design phase of the detector. The spectra shown above are the results of simulations of mono-energetic γ-rays (left) and neutrons hitting a gold sample on a beryllium backing (right) respectively. Even though the Be-backing was heavier than the gold, using the expected good energy resolution, demonstrated in the left figure, a discrimination of the background using the full energy information is possible.



As discussed above, present facilities will be able to measure neutron capture cross section on isotopes with half lives greater than 1000 d. In order to understand the nucleosynthesis correlated with neutron captures in explosive scenarios, it is necessary to gain information about isotopes with much shorter half lives. The method in the picture above is an indirect measurement. A deuteron target will be bombarded with radioactive ions. Measuring the (d,p) cross section then allows to gain information about the (n,γ) cross section. The limitation of the half lives are given by the limits of the radioactive ion beam (RIB). Proof of principle experiments have been carried out e.g. on ^{14}C.



An improvement of the present situation by two orders of magnitude could be gained by a combination of a Radioactive Ion Accelerator (RIA) with a DANCE like detector. Depending on the neutron source used, samples of 10 µg or 10 d half life would be sufficient. The advantage of this setup would be, that almost all problems related to the transportation of radioactive material could be avoided.



Close to spallation targets tremendous neutron fluxes can be reached. If the half life of the isotope X under investigation is not shorter than 1 d, an equilibrium between production via neutron capture on the neighboring isotope X-1 and destruction via β^--decay will be reached. This allows neutron captures on the isotope X, producing X+1. After a few days of irradiation the activity of X+1 can be analyzed and the X(n,γ) cross section can be determined relative to the X-1(n,γ) cross section. Since only averaged neutron energy information can be gained applying this method, it would be necessary to shape the neutron energy distribution using suited moderator/absorber combinations.