EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of the neutron capture cross section of ^{87}Sr

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Abstract

With this proposal, which is full related to proposal INTC-P-304 [1], we aim to measure the neutron capture cross section of the nucleus ^{87}Sr using C_6D_6 detectors at EAR1 of the n_TOF facility. The first part of the original proposal concerned a gamma-ray spectroscopy experiment with the BaF_2 4π detector array of the total absorption calorimeter. The experiment was carried out and the results have been published. Because of a problem encountered with the sample, the second part of the proposal, which concerned a neutron capture cross section measurement with C_6D_6 detectors, was never performed because of a sample issue. The remains of the sample have been transported to PSI where the feasibility of reconditioning was positively assessed. Work is ongoing to prepare the sample in a state suitable for a capture measurement at n_TOF. The neutron capture cross section of ^{87}Sr is of interest for the astrophysical *s*-process and for the ^{87}Rb/^{87}Sr cosmochronometer.

Requested protons: 2.6×10^{18} / 1.0×10^{18} protons on target
Experimental Area: EAR1 / EAR2

Figure 1. A picture of the ^{87}Sr sample before (left panel) and after (right panel) the previous experiment performed with the TAC.

1 Introduction

In a previous proposal, approved by the INTC [1], we proposed two different experiments in EAR1 with a highly enriched metallic sample of 287 mg of the stable nucleus ^{87}Sr, made available by Los Alamos National Laboratory. The first experiment had the goal to determine the spins of neutron-induced resonances using gamma-ray spectroscopy. Spin distributions are a component of nuclear level densities which are a key ingredient in model-based calculations of nuclear cross sections. The experiment was performed with the total absorption calorimeter (TAC) and we found a dependence of the ratio of two low-lying transitions on the spin of the initial capture state. In this way, spins have been determined for 16 *s*-wave resonances. These results have been published [2].

The initially metallic sample of 287 mg Sr, enriched to 87.7% of ^{87}Sr, was sealed between two layers of kapton under an inert atmosphere in order to prevent oxidation. Nevertheless, some oxygen was either introduced during the sealing process or diffused through the kapton windows since. In fact, we observed that during the measurement the sample became substantially oxidized and fully lost its initial shape and position. While this was not an issue of concern to exploit the data for the purpose of spin assignments based on low-level populations [3, 4], the measurement could not be used to extract the neutron capture cross section. Because of the strongly deteriorated sample, at the time it was decided to put the subsequently scheduled measurement with C_6D_6 detectors on hold until a solution was found.

At present the oxidized sample is located at PSI where the Sr material will be fully transformed into SrO under controlled conditions, pressed into a 20 mm diameter pellet to form a material with a homogeneous areal density, and then repackaged in an aluminium container already produced by JRC-Geel. The container will be sealed. An indication of the homogeneity of the material will be obtained with X-rays.

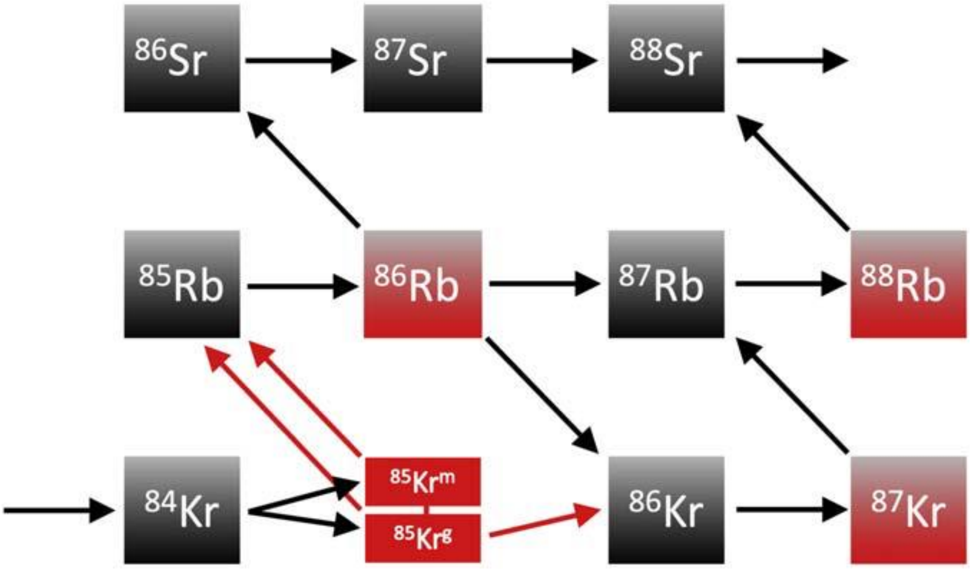

Figure 2. The region of interest on the the nuclear chart showing the Rb-Sr region. The nucleus ^{87}Rb has a half-life of 49 Gy which is considered stable on earth, but has to be taken into account on the time scale of stellar evolution. The figure is from ref. [10].

2 Motivation

The neutron capture cross section of the s-only isotope ^{87}Sr is of importance in the modelling of the astrophysical s-process in the vicinity of the branching point ^{85}Kr [5, 6]. The s-process (slow neutron capture process) nucleosynthesis occurs in asymptotic giant branch (AGB) stars, during late stellar evolution phases. The formation path is a monitor of the stellar neutron density and temperature. This particular region of the stellar nucleosynthesis process is shown in figure 1.

In cosmology, the radioactive nucleus ^{87}Rb (49 Gy) and its stable daughter nucleus ^{87}Sr form a chronometric pair [7, 8]. The ratio of the two nuclei, can be used as a clock to determine the age of stellar objects including stars, planets, and meteorites [9, 10]. In the process of modelling the formation and decay of the nuclei, the neutron capture cross section is important. But due to the currently more uncertain nucleosynthesis process the ^{87}Rb/^{87}Sr pair is however a less favourable clock than the previously investigated ^{187}Rh/^{187}Os clock [11, 12, 13]. The region of the nuclear chart showing the Rb-Sr region is shown in figure 2.

The first large resonance at 3.5 eV was observed by Stolovy and Harvey [14] in a transmission experiment and the total width of this resonance was extracted. Macklin and Gibbons [15] measured the average capture cross section from 30 to 220 keV. Hicks *et al.*[16] used an enriched $SrCO_3$ sample to measure the capture reaction in the keV range from 3 to 30 keV. Walter and Beer [17] also used enriched $SrCO_3$ sample to measure the average capture cross section from 3.5 to 240 keV. Bauer *et al.*[5] measured the capture cross section, reported as a figure from 0.1 to 100 keV, but the original data are not not available in EXFOR [18]. The proposed cross section measurement will cover a large energy range in a single measurement and allows for calculating the Maxwellian averaged

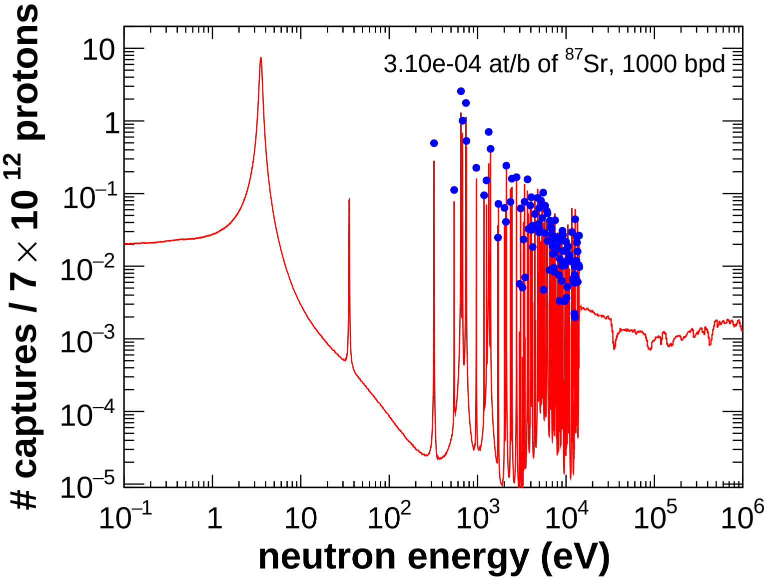

Figure 3. Estimated number of capture reactions per energy bin (red line) and the number of reactions integrated over the resonance area (blue dots) for a nominal beam pulse of 7×10^{12} protons.

capture cross section at the stellar temperatures of interest, with kT typically ranging from 5 to 100 keV.

In addition to the cross section measurement in EAR1, in this proposal we also propose to measure the same sample also in EAR2. This would allow to investigate further the spin assignments based on the low-level population method using gamma-ray spectroscopy with a high resolution detector like a $LaBr_3$ detector. The much higher neutron flux and the use of a gamma-ray detector with a better resolution than BaF_2 likely improves our previous results [2] but also serves as a test to use EAR2 for this method.

3 Experimental setup and count rate estimation

We plan to use a standard capture setup in EAR1 with regular large volume C_6D_6 detectors. An alternative option would to to use the smaller sTED C_6D_6 detectors [19] which have the advantage of being less sensitive to the gamma flash.

An estimation of the number of capture reactions for a nominal bunch of 7×10^{12} protons incident on the ^{87}Sr sample is shown in figure 3. The resolved resonances are Doppler broadened at 300 K. The count rate is based on the expected capture yield and the neutron flux. In the resolved resonance region, the appreciation of the count rate can be best observed from the number of counts integrated over the resonance area. This number is independent of resolution and Doppler broadening and gives a clear estimate of the statistical precision that can be obtained. This number is shown by the blue dots in figure 3.

For the unresolved resonance region the binning, here shown at 1000 bins per energy decade, is a more important quantity. Since the goal here is an averaged cross section which is relatively smooth, a more coarse bining can be used to quantity the experimental data. By the way, the structure we observe in the figure above 10 keV are due to the shape of the neutron flux, which reflects the neutron transmission through the in-beam materials (Al, O) near the neutron target.

The number of requested protons is always a trade-off between measurement duration and statistical precision. The limiting factors are usually the very small resonances and the unresolved resonance region. Assuming an efficiency for detecting a capture reaction of 20%, and using a binning of 20 bins per decade for the unresolved resonance region, a number of 2×10^{18} protons on target would result in about 2000 counts per bin in the unresolved resonance region from the capture reaction. The background in this region, based on previous capture experiments, is expected to be in the order of 50% of the measured spectrum and must be addressed with in-beam filters to determine the absolute level, while the shape will be determined with a carbon neutron scatterer and an empty sample. The in-beam photon-scattered background will be measured with a natural lead sample. We would like to use an additional 0.6×10^{18} protons for the normalization (^{197}Au, ^{nat}Ag, ^{nat}Ir, and background (empty, filters, ^{nat}C, ^{nat}Pb) measurements.

Summary of requested protons: 2.6×10^{18} in EAR1 and 1.0×10^{18} in EAR2.

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

Please describe here below the main parts of your experimental set-up:

Part of the experiment	Design and manufacturing
If relevant, write here the name of the fixed installation you will be using: C_6D_6 detectors present at the n_TOF installation	☒ To be used without any modification ☐ To be modified
If relevant, describe here the name of the flexible/transported equipment you will bring to CERN from your Institute: None	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT

Additional hazard from flexible or transported equipment to the CERN site:

Domain	Hazards/Hazardous Activities		Description
Mechanical Safety	Pressure	☐	[pressure] [bar], [volume][l]
	Vacuum	☐	
	Machine tools	☐	
	Mechanical energy (moving parts)	☐	
	Hot/Cold surfaces	☐	
Cryogenic Safety	Cryogenic fluid	☐	[fluid] [m3]
Electrical Safety	Electrical equipment and installations	☐	[voltage] [V], [current] [A]
	High Voltage equipment	☐	[voltage] [V]
Chemical Safety	CMR (carcinogens, mutagens and toxic to reproduction)	☐	[fluid], [quantity]
	Toxic/Irritant	☐	[fluid], [quantity]
	Corrosive	☐	[fluid], [quantity]
	Oxidizing	☐	[fluid], [quantity]
	Flammable/Potentially explosive atmospheres	☐	[fluid], [quantity]
	Dangerous for the environment	☐	[fluid], [quantity]
Non-ionizing radiation Safety	Laser	☐	[laser], [class]
	UV light	☐	
	Magnetic field	☐	[magnetic field] [T]

Workplace	Excessive noise	☐	
	Working outside normal working hours	☐	
	Working at height (climbing platforms, etc.)	☐	
	Outdoor activities	☐	
Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			