RESEARCH PROPOSAL: CERN / INTC 2000-003
INTC / P117

INVESTIGATION OF THE IMPACT OF THE $^{39}Ar(n,\alpha)^{36}S$ REACTION ON THE NUCLEOSYNTHESIS OF THE RARE ISOTOPE ^{36}S

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1. INTRODUCTION

Since ten years, our group is involved in the study of neutron induced reactions of relevance to primordial and stellar nucleosynthesis.
One of the problems being investigated is the synthesis of the rare, neutron rich isotope ^{36}S in the weak component of the s-process [1,2], for which serious discrepancies occur between observed and calculated abundances [3,4].
Fig.1 shows the reaction network in the neighbourhood of ^{36}S. It illustrates that not only (n,γ) reactions and β-decay, but also (n,p) and (n,α) reactions contribute to the nucleosynthesis of ^{36}S. Several of these reactions have been investigated by us previously: $^{33}S(n,\alpha)^{30}Si$ [5], $^{35}Cl(n,p)^{35}S$ [6], $^{36}Cl(n,p)^{36}S$ [7], $^{40}K(n,\alpha)^{37}Cl$ [8] and $^{41}Ca(n,\alpha)^{38}Ar$ [9]. In these papers, due attention is also given to the spectroscopic information that can be extracted from these reaction studies.
One of the key reactions in this network (since directly leading to ^{36}S) is **$^{39}Ar(n,\alpha)^{36}S$**, which however, has never been studied so far. This is due to the fact that ^{39}Ar is a radioactive ($T_{1/2}$ = 269 y) gas, which is not commercially available.

Recently we have investigated the $^{37}Ar(n,p)^{37}Cl$ and $^{37}Ar(n,\alpha)^{34}S$ reactions at the high flux reactor of the ILL (Grenoble) and the GELINA neutron facility of the IRMM (Geel) [10,11]. Here we had to tackle a very similar sample problem, since also ^{37}Ar is a radioactive gas ($T_{1/2}$ = 35 days!) not being commercially available. These problems could be solved at the cyclotron CYCLONE 30 of the UCL in Louvain-la-Neuve (B), where ^{37}Ar was produced via bombarding ^{37}Cl with 30 MeV protons; the argon was consequently ionised and implanted in a 20 μm thick Al-foil. This method was

very successful and is described in [12]. Last year we modified the operation of the ECR source resulting in a better ionisation efficiency of the argon (20%); in this way samples containing up to $6x10^{15}$ ^{37}Ar nuclei could be prepared. Unfortunately, ^{39}Ar cannot be produced via a similar (p,n) reaction, but we can definitely take profit of our experience with the implantation of ^{37}Ar.

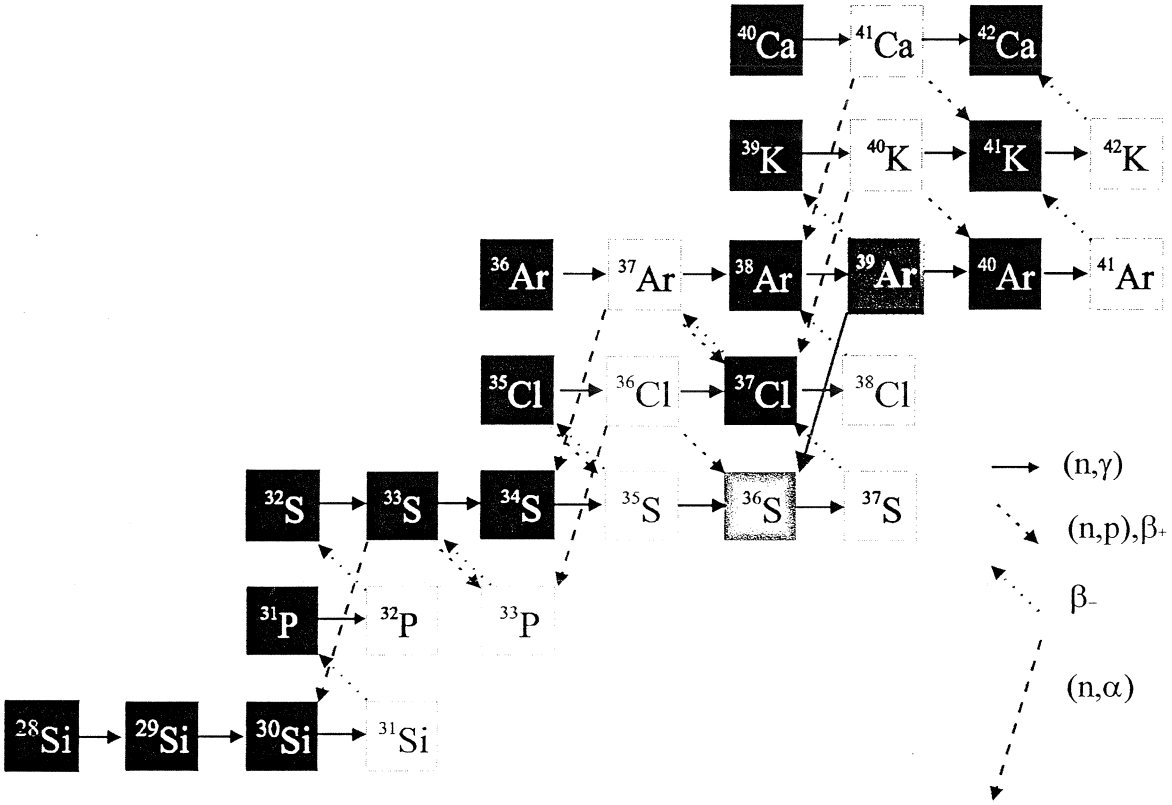

Fig. 1 Nucleosynthesis network in the sulfur region.

2. PROPOSAL

Last November we performed a parasitic 24h test implantation at ISOLDE, using a 5 g/cm^2 CaO target with a MK7 plasma ion source and an average proton current of 1.5 μA. In total about $8x10^{12}$ ^{39}Ar atoms were implanted in an aluminium foil. This corresponds to a yield of roughly $6x10^7$ ions per μC.

With this test sample, a first experiment was performed with thermal neutrons at the High Flux Reactor of the ILL (Grenoble). The measurement was done at the curved neutron guide H22D, which provides an almost background-free thermal neutron beam with $5x10^8$ neutrons/cm^2.s. A dedicated setup using suited surface barrier detectors was used. Unfortunately it was interrupted due to an unexpected shutdown of the reactor. Moreover, the detection of the 2.76 MeV $^{39}Ar(n,\alpha)$ – particles was strongly hampered by

the presence of 2.72 MeV background tritons produced by the $^{6}Li(n,\alpha)t$ reaction induced by scattered neutrons in ^{6}Li impurities in the detector environment. Still, based on these incomplete data we roughly estimate the $^{39}Ar(n_{th},\alpha)$ cross-section to be of the order of 1 b. So a sample containing some 10^{14} atoms would enable to perform a good experiment with thermal neutrons. For measurements with resonance neutrons we extrapolate that at least one order of magnitude more atoms will be needed, but this depends on the (unknown) resonance characteristics of the $^{39}Ar(n,\alpha)^{36}S$ reaction.

The experimental conditions used during the test implantation can be significantly improved on various points:

1. In the used CaO target mainly (p,3pxn) spallation reactions from ^{42+x}Ca contribute to the production of ^{39}Ar. The dominant isotope ^{40}Ca (97 % natural abundance) does practically not contribute to the production of ^{39}Ar and thus the effective target thickness for ^{39}Ar production was only about 0.15 g/cm^2. Using an alternative target material for close spallation reactions (Sc, Ti, V or Cr as metal foil or compound) could thus enhance the effective target thickness and the ^{39}Ar production rate in the target by about two orders of magnitude. Decay losses are no problem for a ^{39}Ar collection, therefore any of the mentioned targets could be used. The choice can be adapted for an efficient use of the same target unit for other ISOLDE experiments.
2. Possible beam contaminations (e.g. $^{78}Kr^{2+}$, ^{39}K,...) are not disturbing the cross-section measurement since their (n_{th},α) cross sections are negligible; this is not so for ^{37}Ar, but the $^{37}Ar(n_{th},\alpha)$ - energies are sufficiently different from the $^{39}Ar(n_{th},\alpha)$ – energy to be recognised. Therefore we do not need necessarily a MK7 source with cooled transfer line, but the experiment is also compatible to the use of a medium- or high-temperature plasma ion source.
3. During the test collection the ionization efficiency of the MK7 FEBIAD ion source for argon was of the order of 5 %. An alternative microwave ion source (e.g. Mini-ECRIS) could provide a gain in ionization efficiency by one order of magnitude. Like many other ISOLDE experiments, our experiment would profit from the implementation of such a source at ISOLDE. Therefore we support a proposal aiming for the integration of a high efficiency ion source for light gaseous elements at ISOLDE.

The proposed improvements should allow to collect within 6 shifts a sample with an amount of at least 10^{15} ^{39}Ar atoms. This will be sufficient to measure the (n,α) cross-section with thermal neutrons to a precision of better than 5% and to probe the resonance region up to about 100 keV.

Note that the collection can be performed at the GLM or GHM beam port respectively, in parallel to another experiment operating on the central beam line, if no frequent mass changes are required for the other experiment.

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