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Letter of Intent to the INTC

Direct measurement of the ^{44}Ti(α,p) reaction of importance to supernovae, using reclaimed ^{44}Ti.

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Core collapse supernovae are remarkable astrophysical sites, representing one of the most extreme physics laboratories in Nature. Consequently, there is immense interest in attempting to elucidate the physics that drives them. However, this is made extremely difficult, both by the complexity of the explosion and the fact that the important processes are occurring deep beneath the surface. Major fundamental uncertainties remain, for example, the explosion mechanism itself (is it a neutrino-driven delayed detonation, or perhaps the recently proposed gravity-wave driven acoustic mechanism [1] ?) and whether or not core collapse supernovae are the site of the r-process.

One of the few methods by which the explosion mechanism may be studied in a reasonably direct was is through comparison of the amount of ^{44}Ti observed by satellite via its beta-delayed gamma-ray emission, to the amount predicted to have been generated in the explosion. The importance of ^{44}Ti lies in the expectation that it is synthesised in a process known as alpha-rich freeze out which occurs in the shock-heated silicon layer that lies just above the detonating core [2]. The so-called mass cut also occurs in this region, that is, the boundary between material that is successfully ejected and that which falls back on to the proto-neutron star. Gamma-rays from material that falls back will be unable to escape the dense environment and thus cannot be observed. Hence, the comparison of observed to predicted production provides a measure of the location of the mass cut. The mass cut is a key hydrodynamic property of supernova models, and constraining this would be of immense help in finally understanding the explosion mechanism.

Unfortunately, before the comparison outlined above can be made, the models of core collapse supernova require better nuclear physics inputs. The *et al*. [3] explored which nuclear reactions had most impact on the ^{44}Ti abundances produced in core-collapse supernovae, and found that one of the few reactions that resulted in a significant contribution to the overall uncertainty was the ^{44}Ti(α,p)^{47}V reaction. Despite the obvious experimental difficulties, the astrophysical rate of this reaction has been measured before [4], but at too high an energy to be useful.

A key difficulty is the provision of an intense, low energy radioactive nuclear beam of the isotope ^{44}Ti. Producing these beams from the current generation of ISOL ion-sources is difficult, but an approach in which previously collected ^{44}Ti atoms ($t_{½}$ =60 yrs) are fed into an off-line ion source appears to be highly promising. To this end, the

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Exotic Radionuclides from Accelerator Waste project [5] is an attempt to see what use can be made of the activities that have built up over the years in highly irradiated accelerator parts. The first phase of this involved a used copper beam dump from the 590 MeV ring cyclotron at PSI. This has had an average exposure of 1.5 mA for 12 years. Extraction of ^{44}Ti from this beam dump is now complete. A sample of 10^{16} atoms of ^{44}Ti, in a solution of 20 ml 1M nitric acid, is now collected and is available for the proposed experiment. The previous measurement of this reaction was based on a beam intensity of 5×10^5 pps: extrapolating their level of statistics and measured cross section to lower energies suggests that a few $\times10^{12}$ ions delivered on to a helium gas cell would allow a meaningful measurement at an MeV lower than the lowest energy previous data point. Thus, if this sample of ^{44}Ti ions can be delivered to target with an overall efficiency of $\sim10^{-4}$, a week-long run at a beam current of about 10^6 pps will facilitate an extremely exiting experiment.

It is our desire to conduct such an experiment at REX, injecting these ^{44}Ti atoms into an offline ion source and accelerating them to energies in the range 1 − 2 MeV/A. A small helium gas cell will be used, similar to the one successfully employed by the Edinburgh group for (α,p) measurements at Louvain-la-Neuve, while protons would be detected in the MINIBALL chamber using double sided silicon strip detectors provided by Edinburgh. Coincident gamma-ray measurements are also under consideration.

The purpose of this Letter of Intent is to provide authorisation for the beam development time that is needed to explore the feasibility of delivering the ^{44}Ti beam. Initial discussions with Mats Lindroos and Thierry Stora suggest several ion source configurations which might work, for example, surface ionisation is the simplest method, but may not achieve enough intensity, while a hot FEBIAD plasma ion source will have higher efficiency but CO_2 may be a problem for REX-Trap performance. Offline target tests are required.

Another issue to be addressed is the impact of the use of radioactive ^{44}Ti ions. The small quantity involved means there is little increased health risk so radiation safety should not be a significant issue. However, the 1.157 MeV gamma-ray, so useful for satellite based observations of ^{44}Ti from supernovae, may pose an issue for future users. If so an alternative or newly constructed chamber can be considered.

While we would be ready to proceed essentially as soon as an appropriate beam was available, it is anticipated that a full proposal with an expanded author list will be submitted before any experimental run. The ERAWAST project continues and larger quantities of this, and perhaps other interesting isotopes, may also be available in the future.

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