EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Beta decay of the *N=Z*, rp-process waiting points: ^{64}Ge, ^{68}Se and the *N=Z+2*: ^{66}Ge, ^{70}Se for accurate stellar weak-decay rates

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Abstract

The contribution of electron capture to weak-decay rates has been neglected in model calculations of Type I X-ray bursts so far. Nucleosynthesis in these astrophysical events eventually proceeds through the rp-process near the proton drip-line. In particular, several N=Z nuclei such as ^{64}Ge and ^{68}Se act as waiting points in the nuclear flow due to the low S_p values of their *Z+1* neighbours. Recent theoretical calculations have shown that, in these high density (~10^6 g/cm3) and high temperature (1 - 2 GK) scenarios, continuum electron capture rates might play an important role, in particular for species at and around these waiting point nuclei. This proposal is aimed at the study of the β^+/EC-decay of the waiting point nuclei ^{64}Ge, ^{68}Se and their *N=Z+2* second neighbours ^{66}Ge and ^{70}Se with the Total Absorption Spectroscopy method. This will allow for a detailed analysis of their contribution to the EC-decay rates in X-Ray burst explosions. The proposed spectroscopy study would provide a benchmark for testing models under terrestrial conditions that can be used later for predictions in stellar conditions.

Requested shifts: 12 shifts, (split into 1 run over 1 year)

Physics Case

Nucleosynthesis in explosive hydrogen burning at high temperatures (T > 10^8 K) is characterized mainly by the rapid proton capture (rp-) process [WAL81]. Discussions of the possible scenarios for such extreme conditions can be found in Ref. [SCH98] and [SCH06], where Type I X-ray bursts (XRBs) are suggested as possible sites for the rp-process. These explosions are produced in binary systems in which a neutron star accretes hydrogen-rich material from a low-mass companion star, typically a Main Sequence or a Red-Giant star. Thermonuclear ignition takes place in semi-degenerate conditions, when the temperature and density in the accreted envelope become high enough to allow for a breakout from the hot CNO cycle. Nucleosynthesis eventually proceeds near the proton drip-line via the rp-process [PAR13]. Type I XRBs are characterized by T_{peak} = 1 – 3 GK and $\rho = 10^6 - 10^7$ g cm^{-3}. About 100 systems exhibiting these phenomena have been discovered to date.

XRB sources show persistent X-ray luminosities of ~10^{36} - 10^{38} ergs s^{-1}. During the bursts, luminosities of ~10^{39} ergs s^{-1} are reached. The time scale of the Type I XRBs ranges from 3 to 1000 s, during which there is a sharp rise in luminosity within the first second, typically a factor of 100 with respect to the normal luminosity, followed by a gradual softening until the normal luminosity is recovered in about 100 - 1000 s (see Fig. 1, taken from Ref. [LEW93], for an example). The process usually recurs in a time scale of ~10^3 - 10^6 s. A discussion on the main features and observations of XRBs, luminosity curves and interesting new discoveries can be found in Ref. [LAM00][PAR13].

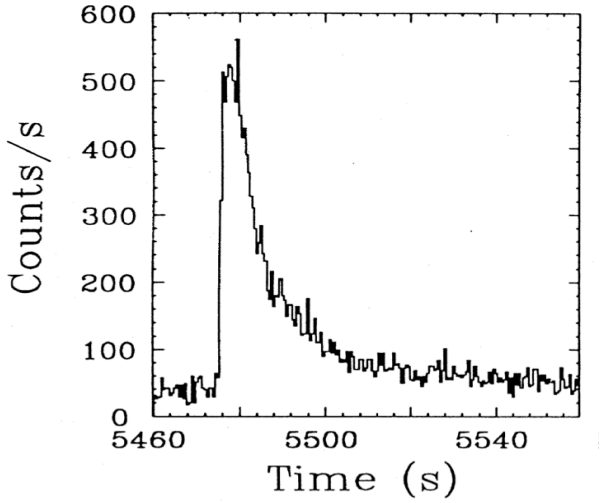

Fig. 1 *X-ray burst from 1702-429 observed with EXOSAT in the 1.2 - 5.3 keV energy band. Taken from Ref. [LEW93].*

Within the scenario described above, the rp-process reaction path follows a series of fast (p,γ) reactions as long as the proton capture reaction rates are orders-of-magnitude faster than the main competing process of β-decay. When the path approaches the proton drip-line further proton capture is inhibited by a strong reverse photodisintegration reaction or by direct proton emission. At this stage the reaction flow has to wait for the relatively slow β-decay process, and the nucleus concerned is called a Waiting Point (WP). As the time scale for the rp-process is of the order of 100 s, any delay of several seconds due to the β-decay half-lives involved affects the process considerably and, therefore, any physical observable that arises from it. In particular it affects the nuclear energy production rate, which in the end, translates into the luminosity curves observed during the XRBs. This is the main physical observable for XRBs to which model predictions can be compared. In this context, an accurate knowledge of the weak decay rates (β^+/EC-decay rates) of the WP nuclei and their neighbours is of paramount importance for the performance of detailed model calculations that can reproduce and explain the physical observables of the XRBs [SCH98]. However, we are far from having an accurate knowledge of the weak-decay rates close to the proton drip-line [SCH98][FIS09][JOS10].

No XRB model calculation to date has consistently included the EC component of weak interaction rates for all nuclei encountered in the corresponding nuclear flow. The reason is the following: at the peak conditions of temperature and density of the rp-process, nuclei are completely ionized and the electron capture process can only occur with free electrons from the continuum, a process that is referred to as continuum Electron Capture (cEC). This process was considered to be negligible in [SCH98] since the density in the XRBs environment is considered to be relatively low ($\rho \sim 10^{6.5}$ g cm^{-3}) and hence irrelevant. However, it was shown by Sarriguren in [SAR09], and pursued later by Nabi in [NAB12], that the cEC process plays an important role in the weak-decay rates of nuclei close to the proton drip-line in XRB calculations. In particular, the cEC-decay rates of the WP nuclei ^{76}Sr and ^{72}Kr are calculated to be very similar to the β^+-decay rates, and for their N=Z+2 neighbours the cEC-decay rates are even higher, up to one order-of-magnitude in ^{74}Kr, than the β^+-decay rates. In order to validate their calculations, both authors have used our experimental results for ^{74}Kr, ^{76}Sr and ^{78}Sr obtained from the data taken with the Total Absorption Spectrometer called *Lucrecia* at ISOLDE-CERN [POI04][NAC04][PER12]. Indeed, these experimental results are part of the input for the calculations of Ref. [NAB12]. During this first campaign the decay of the WP nucleus ^{72}Kr was also measured with

Lucrecia at ISOLDE-CERN. The analysis of this decay is finished and the results will be submitted for publication soon.

In a further set of calculations [SAR11] it has been shown that, for the lighter WP ^{64}Ge and ^{68}Se the cEC-decay rates are higher than the β^+-decay rates by a factor of 2, and in the case of their N=Z+2 neighbours this factor grows by as much as 100 (see Fig. 2). It is therefore of prime importance that the β^+/EC-decay of these nuclei, which is not very well known, is measured properly to validate the calculations. In particular, a good determination of the B(GT) distribution of their β-decay in terrestrial conditions is absolutely necessary to validate the calculations of Ref. [SAR11]. Quoting the author of Ref. [SAR09]: *"Although these decay properties (B(GT) distributions and half-lives) may be different at high ρ and T existing in rp-process scenarios, success in their description under terrestrial conditions is a requirement for a reliable calculation of the weak decay rates in more general conditions"*. Unfortunately, the β-decays of ^{64,66}Ge and ^{68,70}Se are not well known. In particular, there is very little spectroscopic information on the decay of the WP nuclei ^{64}Ge and ^{68}Se. The Q_{EC} value of the former is 4517 keV [AUD12] and of the latter 4705 keV [AUD12]. However, the highest populated level in ^{64}Ga has been reported at 775 keV [ROB74], and the corresponding one in ^{68}As is at 426 keV [BAU94]. This lack of information on the rest of the Q_{EC} window for both decays is due to the low gamma efficiency of the experimental setups. This is why no B(GT) distribution is given in any of the cited references. Under these circumstances the Total Absorption Spectroscopy (TAS) measurement seems to be the most adequate approach to provide meaningful information in this region (See Ref. [Rub05] and references therein).

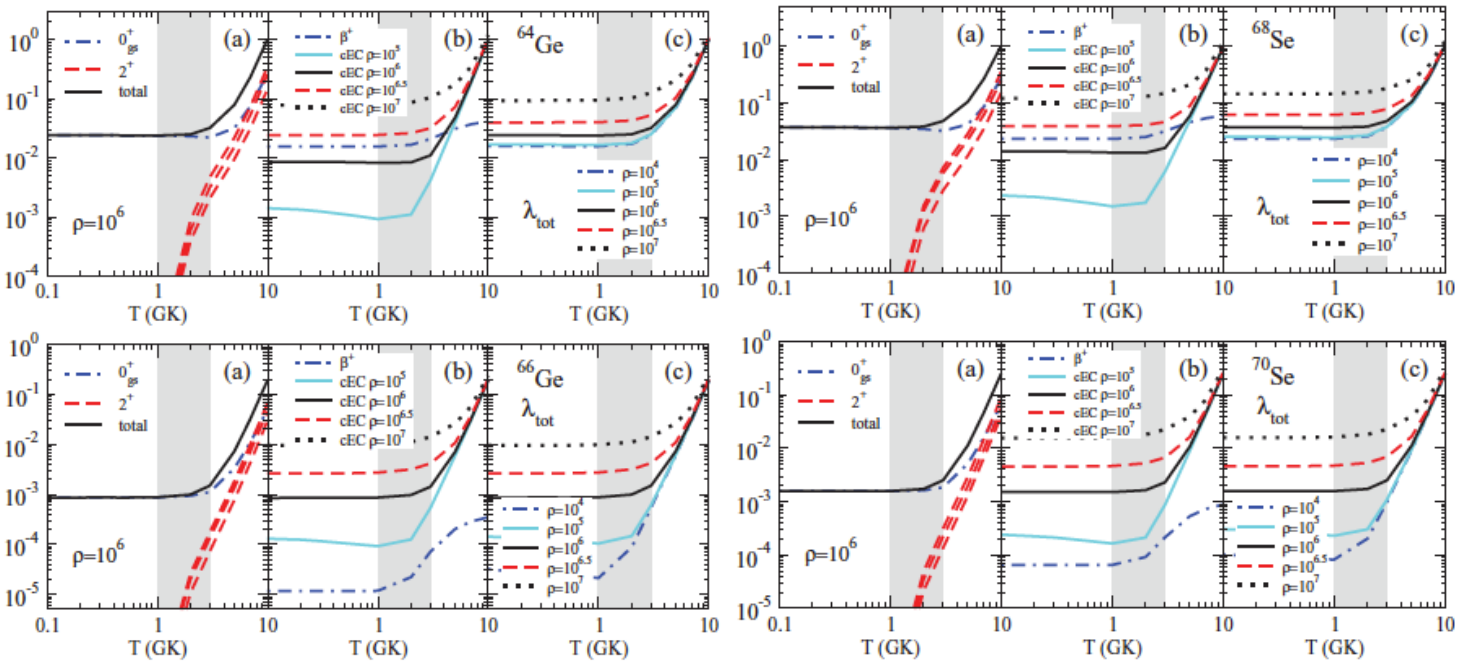

Fig. 2 *Decay rates in s^{-1} of ^{64,66}Ge and ^{68,70}Se as a function of the temperature. Taken from Ref. [SAR11]. (a) Decomposition of the total rates into their contributions from the decays of the ground state and excited 2^+ states. (b) Decomposition of the rates into their cEC and β^+ components, evaluated at different temperatures. (c) Total rates at various densities. The label ρ stands for $\rho Y_e(mol/cm^3)$*

In order to test the effect of including the cEC-decay rates calculated by Sarriguren in [SAR11] in rp-process network calculations, we have made a calculation of the nuclear energy generation rate through post-processing one XRB thermodynamic history, following the procedure in [PAR08][KOI04]. These calculations are adequate to explore the sensitivity of predictions to the nuclear physics input, although more sophisticated hydrodynamic models [WOO04][JOS10] are needed to rigorously examine detailed effects on predicted XRB luminosities.

First: a "standard" calculation has been run (that is, standard rates for all reactions and weak interaction rates, neglecting the cEC component). Secondly: a test calculation where the standard weak-decay rates of the eight isotopes of interest (^{64,66}Ge, ^{68,70}Se, ^{72,74}Kr, ^{76,78}Sr) were all multiplied by a uniform factor of 10 to simulate the inclusion of the cEC component.

The corresponding calculated nuclear energy generation rates for these two cases are shown in Fig. 3. The energy generation rates are in remarkable agreement except towards the later times for the computed burst (above t~10 s in Fig. 3), when the calculation with the enhanced weak rates produces more energy than the standard calculation. This is reasonable given that the relevant high mass species are only produced late in the burst (with half-lives, for the WP nuclei, of 9 - 64 s).

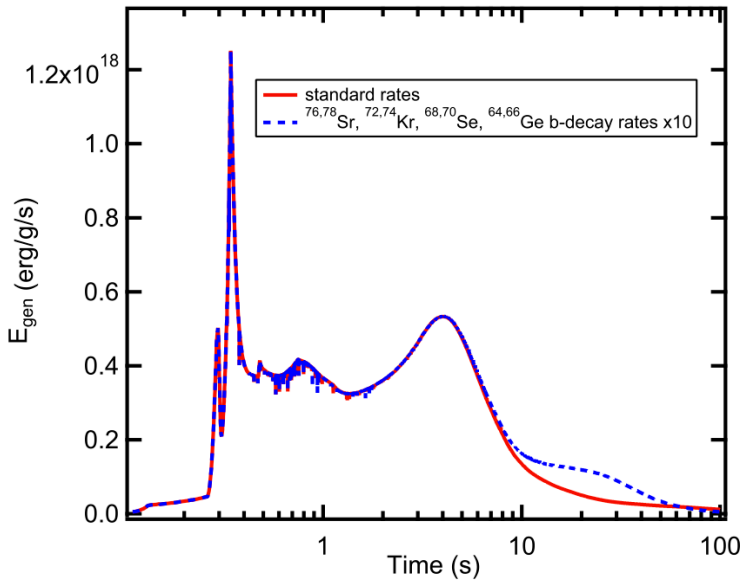

Fig. 3: *Comparison of the nuclear energy generated in one XRB model (K04 in Ref.[PAR08]) taking into account the standard weak-decay rates that neglect the cEC component (red), and simulating the cEC component just by multiplying the standard weak-decay rates by 10 for the isotopes of interest:* ^{64,66}Ge, ^{68,70}Se, ^{72,74}Kr, ^{76,78}Sr

There are obviously limitations to this test calculation. More XRB profiles should be used. The change in rates should be done using the actual calculations from, e.g., [SAR11], and for all species in the network. Nonetheless, we see that even enhancing weak interaction rates for a few species by a factor of 10 has a clear effect on the nuclear energy generation rate in our model. For some species, the calculations of [SAR11] differ from standard beta decay rates by a factor of 100 or more. Given the astrophysical impact of including improved weak interaction rates in XRB models, theoretical models for cEC rates must be validated. We propose to test these models by measuring the important EC rates of nuclei at and around the XRB waiting points: ^{64,66}Ge and ^{68,70}Se.

Experimental Technique

In this proposal we aim to determine the B(GT) distributions in the decay of several neutron-deficient nuclei in the A=70 region. Even though one might think that the important physical quantity, as far as XRB model calculations is concerned, should be the half life, this gives very limited information on the nuclear structure. In fact, different B(GT) distributions obtained with different models might lead to the same half life. Therefore, in order to validate a theoretical model one has to compare calculations with experimental B(GT) distributions rather than β-decay half-lives.

For the study of the β-decay of ^{64,66}Ge and ^{68,70}Se and the determination of their respective B(GT) distributions we plan to use the Total Absorption Spectrometer (TAS) *Lucrecia*, installed at ISOLDE-CERN since the year 2001. It consists of a large NaI(Tl) crystal of cylindrical shape (l=Ø=38 cm) with a cylindrical hole perpendicular to the symmetry axis. The transverse hole allows us to take the activity to the centre of the crystal and it also makes possible the placement of ancillary detectors in close geometry to the sources (see Fig. 4). The total efficiency of the TAS has been estimated, using Monte Carlo methods, to be ~ 90 % for mono-energetic gamma rays of 300-3000 keV energy, which gives an approximate 99 % total efficiency for gamma cascades of more than one gamma ray.

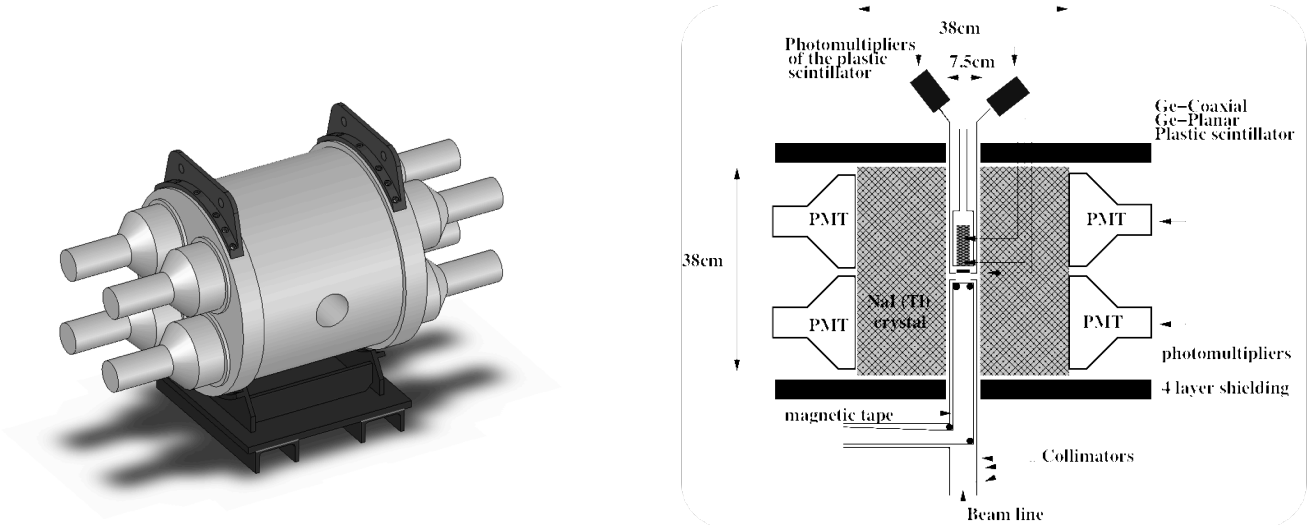

Fig. 4: *Left panel: a realistic 3D model of Lucrecia where one can see the main NaI cylinder, the transverse hole and the eight photomultiplier tubes. Right panel: A horizontal cut of the detector where the placement of the beam line and ancillary detectors is shown. Figures taken from Ref. [PER12].*

The main goal of the TAS technique, which is also its main advantage with respect to the traditional high-resolution technique with HPGe detectors, is to measure entire gamma cascades rather than individual gamma-rays [Rub05]. In an ideal case this would give us directly the beta intensity distribution of the measured decay. However, in a real TAS one has to account for a non-perfect response function of the detector mainly due to the limitations in geometry as well as the amount of dead material between the radioactive

source and the active volume of the TAS. Thus, a gamma-ray spectrum measured with a TAS detector does not represent directly the beta intensity distribution but the former multiplied by the response function of the detector.

Therefore the analysis of the TAS data requires the solving of the $d=R(B)f$ inverse problem, where d represents the measured data (free of contaminants), $R(B)$ is the response matrix of the TAS detector, which depends on the branching ratios of the levels in the daughter nucleus (B), and f is the beta intensity distribution, which is the quantity we want to measure. To construct the branching ratio matrix B the standard procedure is to use the known low-lying levels and branching ratios from previous high-resolution experiments done with HPGe detectors. This is valid up to a certain excitation energy. From this energy on, one has to use a statistical model to construct the "unknown" or high-lying part. Once we extract the beta intensity distribution f from our experimental data, the B(GT) distribution is easily determined as long as the Q_{EC} and half-life of the decay are well known.

The analysis of the TAS data will be carried out using the unfolding iterative Expectation-Maximization algorithm adapted to the particular case of TAS by the Valencia group [TAI07]. The application of these methods will allow one to determine the B(GT) in a reliable way up to the limit of the Q_{EC} as in the earlier cases studied with the *Lucrecia* spectrometer [NAC04][POI04]. In order to apply these unfolding methods reliably, one has to estimate very accurately the components that we see in our spectrum that do not correspond to the decay of interest, namely the pile-up events, the room background and the activity of the daughters. The pile-up can be treated properly following Ref. [CAN99], but for the other two components we need separate measurements of daughter activity as well as periodic room-background measurements in identical conditions to the main decay measurement.

Production

For the production and separation of ^{68,70}Se we propose to use either an Y_2O_3 nanomaterial or a ZrO_2 fibre target coupled to the recently developed arc discharge VD5 source (VADIS) [PEN09]. The isotopes of interest will be extracted in the molecular SeCO sideband. This method has been proven to produce Se beams isotopically much purer than the direct extraction of Se, which would be contaminated by isobars [KOS03].

From the recent experience of production of $^{73}SeCO^+$ from the Y_2O_3 nanomaterial target unit [STO11], and the measurements of $^{70}SeCO^+$ produced from ZrO_2-MK5 unit [HUR07] a production rate in the range of 100-200 **^{68}Se** ions/μC is expected. We note that at the ISOLDE-SC the ^{68}SeCO yield was about 120 ions/μC [BAU94], but this value was not reproduced with ZrO_2-MK5 target units at the PSB. A yield measurement for the Y_2O_3-VD5 target/ion-source unit is thus requested for this beam within the ISOLDE Target and Ion Source Development (TISD) programme. At the mass of $^{68}SeCO^+$ (A = 96), contamination by stable ^{96}Mo ions from the source may appear, but they are not harmful for our measurement. With the estimated production yield we require 4 shifts to measure the isotope of interest and 2 for the measurement of the daughter contaminant. Prior to the measurement we request the assessment of the production of ^{68}Se.

The production of **^{70}Se**CO^+ with these target/ion-source systems is sufficient for the experiment since it is expected to be at least 3 orders-of-magnitude larger than ^{68}Se. In a recent experiment a yield of 6 x 10^5 ^{70}SeCO ions/μC was reported [HUR07]. Thus, our

measurement will be limited by the maximum counting rate we can handle with the TAS detector. We estimate 2 shift of beam for this measurement and 1 shift for the measurement of the daughter activity.

As far as production and separation of Ge is concerned, **^{66}Ge** is also well produced (3.5 x 10^5 ions/μC) with the ZrO_2-MK5 target/ion-source combination [KOS03]. Therefore one might expect an improved yield with the Y_2O_3-VD5 target/ion-source. In this case, the extraction of the molecular form GeS would be used at mass 34+66 instead of direct Ge at mass 66 as the latter would be highly contaminated with Ga. The production of ^{66}Ge and the use of the combination of two leaks (for CO and for S) can be assessed during the beam time dedicated to the production test of the Y_2O_3-VD5 requested above. The production yield of **^{64}Ge** with this novel target unit should be also measured. With this target/ion-source combination the experimental measurement of ^{66}Ge can be achieved in the same run as ^{68,70}Se. Again, 2 shifts should be devoted to measuring the decay of ^{66}Ge and 1 to the decay of the daughter.

It should be noted that ^{64,66}Ge can be produced by a Y_2O_3 or ZrO_2 target coupled to the ISOLDE RILIS, employing the recently available Ti:Sa lasers. The development of ionization scheme for Ti:Sa lasers was carried out at ORNL [LIU06][KES07] and was successfully applied at TRIUMF for on-line measurements in 2011 [SIM12]. The Ge ionization efficiency was measured to be 3.3% at ORNL [LIU06]. Since the RILIS laser installation is capable to produce more powerful laser beams we can expect that at ISOLDE Ge can be ionized more efficiently (eventually a new and more efficient ionization scheme using the dual RILIS laser setup could be developed). However the actual yields of ^{64,66}Ge can only be measured in a dedicated on-line beam time. In addition, the ionization efficiency by ISOLDE RILIS can be determined in a standard procedure using a sample of stable Ge isotopes. To this end an on-line yield measurement would be required. Moreover, due to the expected strong contamination by surface-ionized ^{64,66}Ga, the experiment may only be possible with the use of the Laser Ion Source Trap (LIST), thereby reducing the overall Ge yield. Thus, we request a test and fine-tuning of the RILIS ion source as well as yield estimates of ^{64,66}Ge and ^{64,66}Ga prior to our TAS measurement, within the TISD program. Depending on the delivered yields, we will present an addendum to this proposal requesting the necessary number of shifts.

Summary of requested shifts:

6 shifts to measure ^{68}Se and its daughter.

3 shifts to measure ^{70}Se and its daughter.

3 shifts to measure ^{66}Ge and its daughter.

A total of **12 shifts** are requested in this proposal. Shifts for the measurements of ^{64,66}Ge will be requested in an addendum once the results of the two ion-source tests proposed here give us a realistic estimate.

References:

[AUD12] G. Audi et al., Chinese Phys. C 36 (2012) 1287

[BAU94] P. Baumann et al., Phys. Rev. C 50 (1994) 1180

[CAN99] D. Cano-Ott et al., Nucl. Inst. and Methods A 430 (1999) 488

[FIS08] J.L. Fisker, et al., Astrophys. J. Suppl., 174 (2008) 261

[HUR07] A.M. Hurst et al., Physical Review Letters 98 (2007) 072501

[ISODB] ISOLDE Yield Database at http://isolde.cern.ch

[JOS10] J. Jose et al., Astrophys. J. Suppl. 189 (2010) 204

[KOI04] O. Koike et al., Astrophys. J. Lett. 603 (2004) 242

[KOS03] U. Köster et al., Nucl. Inst. and Methods B 204 (2003) 303

[KES07] T. Kessler et al., J. Phys. B 40 (2007) 4413

[LAM00] D.Q. Lamb, Astrophys. J. Suppl. 127 (2000) 395

[LEW93] W.H.G. Lewin et al., Space Sci. Rev. 62 (1993) 223

[LIU06] Y. Liu et al., Nucl. Inst. and Methods B 243 (2006) 442

[NAB12] Jameel-Un Nabi, Astrophys. Space Sci. 339 (2012) 305

[NAC04] E. Nacher et al., Phys. Rev. Lett. 92 (2004) 232501

[PAR08] A. Parikh et al., Astrophys. J. Suppl. 178 (2008) 110

[PAR13] A. Parikh et al., Prog. Part. Nucl. Phys. 69 (2013) 225.

[PEN09] L. Penescu et al., CERN-EN-Note-2009-001 STI

[PER12] A.B. Perez PhD thesis, Univ. de Valencia (2012). Submitted to Phys. Rev. C

[POI04] E. Poirier et al., Phys. Rev. C 69 (2004) 034307

[ROB74] R.G.H Robertson et al., Phys. Rev. C 9 (1974) 1801

[Rub05] B. Rubio et al., J. Phys. G 31 (2005) S1477

[SAR09] P. Sarriguren, Phys. Lett. B 680 (2009) 438

[SAR11] P. Sarriguren, Phys. Rev. C 83 (2011) 025801

[SCH98] H. Schatz et al., Physics Reports 294 (1998) 167

[SCH06] H. Schatz et al., Nucl Phys A 777 (2006) 601

[SIM12] M.C. Simon et al., Rev. Sci. Instrum. 83 (2012) 02A912

[STO11] T. Stora, private communication

[TAI07] J. L. Taín et al., Nucl. Inst. and Methods A 571 (2007) 728

[WAL81] R.K. Wallace et al., Astrophys. J. Suppl. 45 (1981) 389

[WOO04] S. Woosley et al., Astrophys. J. Suppl. (2004) 75

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment)*

Part of the Choose an item.	Availability	Design and manufacturing
TAS station	☒ Existing	☐ To be used without any modification ☒ To be modified (The Tape Station should be updated)

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH] installation.

Additional hazards:

Hazards			
	[Part 1 of the experiment/equipment]	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure			
Vacuum	High Vacuum [10^{-6} mbar]		
Temperature	LN2 temperature [77 K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid			
Electrical and electromagnetic			
Electricity	4.0kV (HPGe det. HV supply)		
Static electricity			
Magnetic field			
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material			
Beam particle type	Ions : 68Se, 70Se, 66Ge		
Beam intensity	200 s^{-1}, 10^5 s^{-1} & 10^5 s^{-1} resp.		
Beam energy	60 keV		
Cooling liquids			
Gases			
Calibration sources:	☒		
• Open source	☐		
• Sealed source	☒ [ISO standard]		
• Isotope	^{152}Eu, ^{133}Ba, ^{22}Na, ^{241}Am, ^{60}Co		
• Activity	1 – 10 kBq		
Use of activated material:			
• Description	☐		
• Dose rate on contact	[dose][mSv]		

and in 10 cm distance			
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

2.5 kW