EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Properties of low-lying intruder states in ^{34}Al and ^{34}Si sequentially populated in beta-decay of ^{34}Mg

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Abstract

A low-lying long-lived (26±1 ms) isomer in ^{34}Al has been observed recently [1] and assigned as 1^+ state of intruder character. It was populated in ^{36}S fragmentation and feeds, in β-decay, the 0_2^+ state in ^{34}Si whose excitation energy and lifetime were determined in an electron-positron pairs spectroscopy experiment. In the present experiment we intend to measure for the first time the gamma rays following the β-decay of ^{34}Mg. Despite the interest for ^{34}Mg, the up-right corner of the "N~20 island of inversion", the only information on its β-decay is the lifetime of 20±10 ms, determined from β-neutron coincidences. As results of proposed experiment, we expect to place the first transitions in the level scheme of ^{34}Al and to strongly populate the newly observed isomer, measuring its excitation energy, if the branching ratio to 4^- ground state is significant. Theoretical estimations for the β-decay of the new isomer indicate strong feeding of low spin states in ^{34}Si. Establishing this additional β-decay scheme will represent a complement to previous studies of ^{34}Al g.s. decay at ISOLDE and will give access to new information on excited states in the double magic ^{34}Si nucleus. In particular, the aim is to measure the intensity of the $2^+_1 \rightarrow 0^+_2$ transition in ^{34}Si in order to extract the B(E2: $0^+_2 \rightarrow 2^+_1$) to better understand how the deformation evolves from ^{36}S towards ^{32}Mg.

Requested shifts: 21 shifts, split into 1 runs over 1 years

Motivation

The interest for neutron-rich N~20 nuclei dates back to the measurement of C. Thibault [2] when a region of strong deformation, unpredicted by *sd*-shell model, was discovered around ^{31}Na. Explained qualitatively by the fact that the ground states are dominated by neutron excitation across the N=20 shell gap, this region was therefore labelled [3] "island of inversion" and attracted, together with its neighbourhood, particular theoretical and experimental attention in the attempt for quantitative understanding of the mechanisms of the N=20 magicity disappearance and the evolution of the deformations, shape coexistence and configurations mixing in the ground and excited states.

The ^{34}Mg(N=22) nucleus is considered as the heaviest in the "island of inversion". Its strong deformation ($\beta \sim 0.54$) was derived from the low excitation energy (660±1 keV) of 2_1^+ state [4] and large B(E2, 0_1^+(g.s.)$\rightarrow 2_1^+$)= 541±102 e^2fm^4 [5,6]. The β-decay of ^{34}Mg has been studied only a long time ago at ISOLDE [7] using a set-up limited to β-delayed neutron probabilities measurement. The life-time of 20±10 ms could be determined, while the P_n/P_{2n} and gamma rays were not measured. Actually, ^{33}Mg is heaviest Mg isotopes studied in beta-gamma spectroscopy [8]. The β-n and β-2n probabilities in ^{34}Mg are expected to be large, taking into account the $Q_\beta(^{34}\mathrm{Mg})$=11.7 MeV, $S_n(^{34}\mathrm{Al})$=2.47 MeV and $S_{2n}(^{34}\mathrm{Al})$=8.01 MeV. Comparing to nearby nuclei we will assume, for the purpose of the counting rates estimation below, that P_n+P_{2n}=50%.

Concerning the ^{34}Al (N=21), no experimental level scheme is available. A 657 keV transition has been observed in a Coulomb excitation experiment [9], however it was not placed in the scheme since it was not possible to establish that the transition final state is the ground state. In recent experiment in GANIL [10] several transitions were assigned to ^{34}Al, but no level scheme was inferred. The measured magnetic moment of the ground state [11] confirmed the 4^- assignment from β-decay [12,13]. The first excited states calculated in [11] with Monte Carlo Shell Model (MCSM) using SPDF-M interaction are shown in Figure 1. The ground state is considered as the lowest energy member of the multiplet generated by $[\pi(d_{5/2})^{-1}\ \nu(f_{7/2})^1]$ coupling with an important admixture *2hω*. The 1^+ state has an intruder *1hω* $[\pi(d_{5/2})^{-1}\ \nu(d_{3/2})^{-1}\nu(f_{7/2})^2]$ origin with some admixture of *3hω* configurations. Its excitation energy is predicted very low, such that the E3 gamma transition toward the ground state will have a partial lifetime of hundreds of ms, much larger than the beta-times known in the region.

The theoretical prediction of such a 1^+ isomer in ^{34}Al was recently confirmed [1] in an experiment performed in GANIL. It was populated through "one neutron pick-up + three proton removal" reaction channel using a ^{36}S beam at intermediate energy (77.5 MeV/A). Its decay toward the 0_2^+ state in ^{34}Si allowed to:

- obtain the energy excitation of the 0_2^+ state in ^{34}Si, deduced from electron-positron pairs energy measurement
- measure the life-time 28(1) ns of 0_2^+ in ^{34}Si, and deduce the reduced monopole transition strength $\rho^2(E0, 0_2^+\rightarrow 0_1^+(g.s))$= 13(1) x 10^{-3}
- deduce the 1^+ character of beta-isomer in ^{34}Al and measure its half-live of 26(1) ms

Nevertheless, the excitation energy of the 1^+ isomer was not measured and the $B(E2;0^+_2\rightarrow 2^+_1)$ has been extracted with a very large uncertainty which therefore do not allow to make a detailed analysis.

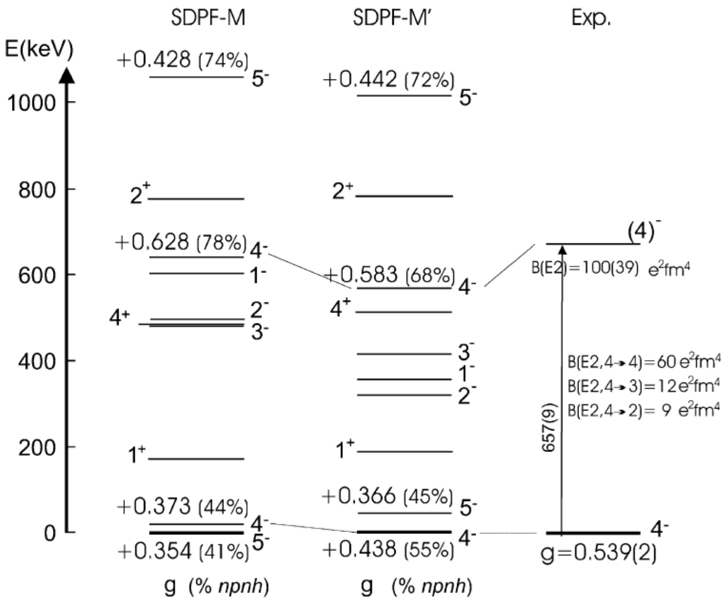

Figure 1. The MCSM calculations for ^{34}Al [11]. On the right side, the transition reported in [9] is tentatively placed.

Figure 2 summarizes the exiting data on ^{34}Al β-decay. In the new experiment at GANIL the half-live of the ground state was measured to be 54.4(5) ms, consistent within 2σ with the previous values obtained at ISOLDE [12,13]. Some of the β-times spectra gated on various gamma transitions in ^{34}Si yielded slightly smaller values, indicating that the isomer feeds higher states as well. However, it was not possible to determine the relative feeding from the isomer.

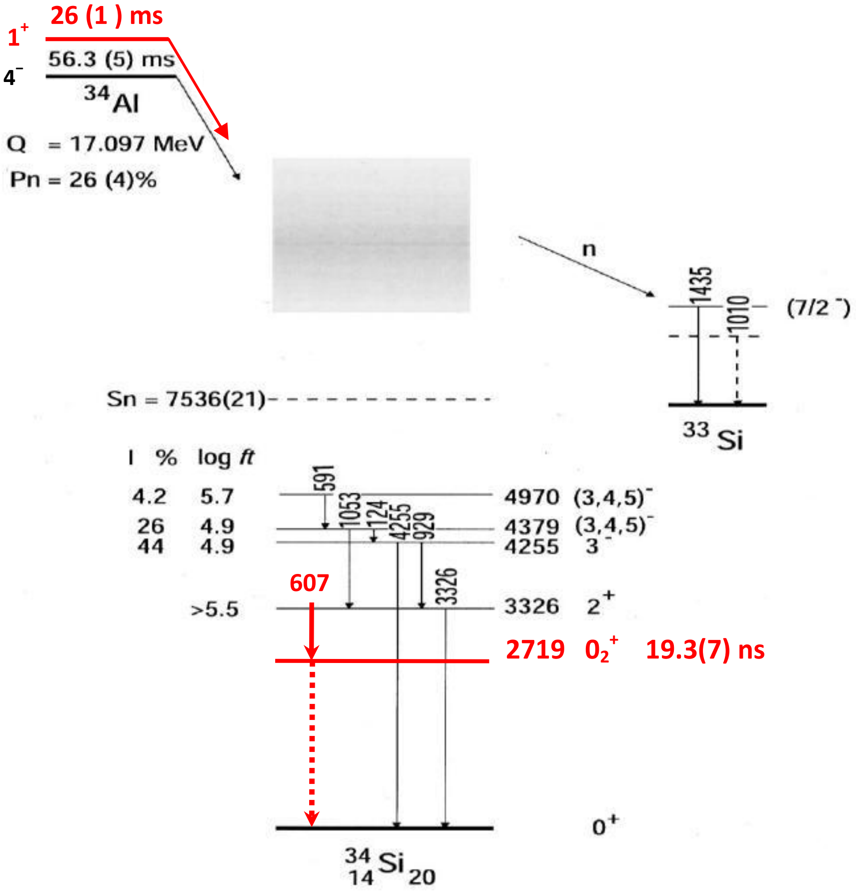

Figure 2. The β-decay data on ^{34}Al from ref. [13] completed in red with the new information from [1].

In the present experiment, the 0^+ ground state of ^{34}Mg is expected to feed strongly the 1^+ isomer in ^{34}Al and, in the next beta-decay step, the low spin positive parity states in ^{34}Si, as shown by the shell model calculations in Figure 3. Contrary to MCSM results, these calculations predict an important gamma branching for 1^+ isomer, which gives the possibility to measure its excitation energy, a very important quantity in understanding effective single particle energies evolution in N~20 neutron rich-nuclei. In both cases, the beta-decay of 1^+ isomer is high and will allow to obtained additional information on ^{34}Si. Due to its double closed shell character in the vicinity of the island of inversion, ^{34}Si is one of the benchmark for all types of theoretical approaches used to describe *sd-pf* nuclei. The recently observed 0_2^+ has a $2\hbar\omega$ intruder character with predicted oblate deformation, while the ground state is spherical (closed shell configuration). The measured $\rho^2(E0)$ proves the shape coexistence. Among other observables, the branching ratio in the de-excitation of 2^+ and the $B(E2, 2^+ \rightarrow 0_2^+)$ are directly related to degree of deformation and shape mixing. In the mentioned GANIL experiment, this branching was deduced with very large error (±50%) due to the uncertainties in the background subtraction (the 607 keV peak is very close to enlarged 596 keV and 608 keV peaks corresponding to ^{74}Ge excited through neutron inelastic scattering) and in the detection efficiencies for electrons-positrons pairs emitted with an unknown energy-angle correlation. Experimental set-up described in the next section will address both these problems allowing the measurement of the branching ratio with higher accuracy. The $B(E2, 2^+ \rightarrow 0_2^+)$ will be therefore deduced from $B(E2, 2^+ \rightarrow 0_1^+(g.s.))=17(7)$ measured in an intermediate energy Coulex experiment [14]. The second 2^+ state, identified at 5.3 MeV in [15, 16] is expected to be populated as well.

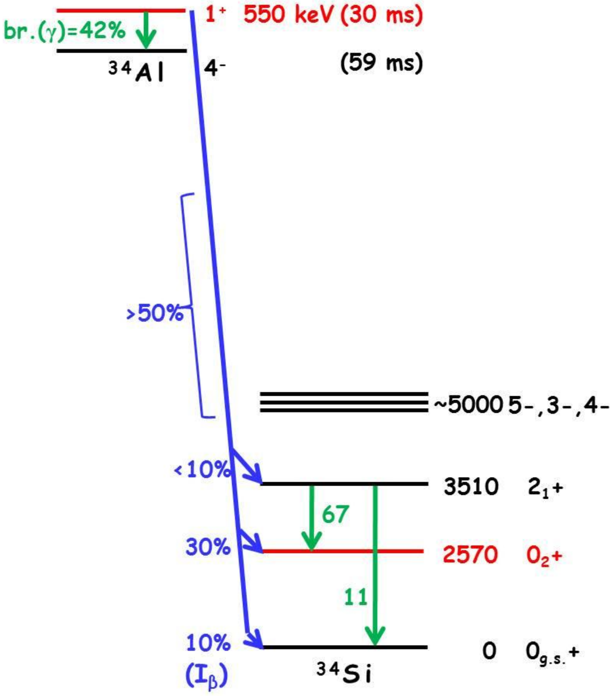

Figure. 3. Shell model calculation in full neutron sd-pf space using the Antoine code and a modified version of the SDPF-U-SI interaction [1][A. Poves, private communication]. The vertical (green) arrows represent the B(E2, down) in e^2fm^4 for corresponding transitions.

Experimental details

The proposed beta-decay experiment will use the fast tape station from IPHC-Strasbourg and a combination of 4 Ge and 4 $LaBr_3$ detectors. The later will be used in order to avoid the interferences of 607 keV peak, corresponding to $2^+ \rightarrow 0_2^+$ transition in ^{34}Si, with ^{74}Ge neutron inelastic scattering peaks, while large volume Ge detectors are employed for high energy (3-4 MeV) gamma rays. The total photopeak efficiencies of $LaBr_3$ detectors will be 2.5% at 0.6 MeV, and that of Ge detectors will be 0.5% at 3 MeV. Neutron detector(s) with an efficiency of 15-20% will be used in coincidence for gamma transition assignation to β-n and β-2n descendants.

Around the implantation point, a fast plastic scintillator coupled to a fast photomultiplier will provide a highly efficient beta trigger (almost 100%). The electron-positron pair from 2.7 MeV E0 decay of 0_2^+ state in ^{34}Si, having a half-life of about 20 ns, will generate a second pulse in the plastic scintillator. A fast discriminator (GHz) will be employed to identify such "double hit in plastic" type of events. The E0 events occurring during the pulse generated by betas(electrons) will give a pile-up and will not be observed. However the pulse width being less than 5 ns, such unobserved E0 events will represent only 20% of the total. Special attention will be given to the efficiency of this filter.

The ^{34}Mg beam is produced from UC_x target using RILIS. The yield mentioned in the ISOLDE database is 140 ions/μC. A improvement by a factor 2÷3, compared to the database values, has been obtained during last years in the yields of other neutron-rich Mg isotopes, less exotic. However, due to the short half-life (20 ms), ^{34}Mg is a difficult ISOL beam. The following counting rates estimate assume a 2 μA proton beam and the yield mentioned above. The release curve parameters of Mg isotopes taken [17], corrected for decay losses, indicate the maximum of implantation rate at about 15 ms after proton bunch arrival and a flat maximum of surviving ^{34}Mg nuclei reached after about 25 ms. In order to measure the decay time curves, the beam will be stopped after 30 ms. Consequently, we expect in average 200/sec implanted ^{34}Mg, of which about 80/sec will decay during the "RIB off" period. The measurement will be done continuously, both during collection and decay periods. The proton bunches repetition rate is supposed 2.4 s and the tape moved just before the each bunch arrival.

Following the β-decay of ^{34}Mg, we suppose that about 50% of the events will populate the 1^+ isomer in ^{34}Al. For comparison, we note that the feeding of 1^+ in ^{32}Al from ^{32}Mg decay is 55%. If low spin states above the isomer will be populated, very probably they will de-excite toward the isomer. Depending on the excitation energy of the isomer and observation of its gamma decay, it will be possible to place such new states in the level scheme. In Figure 3, the isomer is predicted to lay rather high in energy (550 keV) and to have an important gamma branching, which will make possible its observation using a gamma trigger and requesting the absence of beta trigger. In the estimated counting rates given in Table 1, we assume these branching. However, if the state is as lower as predicted by MCSM (see Fig. 3), the gamma branching will be negligible.

New transition may be observed in ^{34}Al and ^{34}Si, down to 1% intensity.

Table 1 . Estimated counting rates for various event types.

Event	Assumptions	Event rate /sec	Detection rate/day
Implanted 34Mg	Beta efficiency is 100%.	200	2E+7
gamma de-exciting the 1^+ isomer	50% isomer feeding 40% gamma branch 2.5% gamma eff.	40	1E+5
Low intensity gamma	1% feeding 2.5% gamma eff.	2	5E+3
Neutron – gamma (low intensity) coincidence	1% feeding 2.5% gamma eff. 5% neutron eff.	2	250
Low intensity gamma cascade	1% feeding 2.5%*2.5% gamma eff.	2	100
3326 keV transition in ^{34}Si	2+ state feeding: 10% from 1+ decay 70% from g.s. decay 0.5% gamma eff.	200*.5*0.6*0.1=6+ 200*.5*0.4*0.7=28 ⇨ Total: 32	1.5E4
607 keV transition in ^{34}Si gated on "double hit in plastic"	2+ Feeding as above, 607 kev branching: 1e-3 2.5 gamma eff. 80% eff. for "double hit in pl."	Total: 3.2e-2	60
Feeding of 0_2^+ in ^{34}Si	30% feeding from 1+ decay 80% eff. for "double hit in pl."	200*0.5*0.6*0.3=18	1.2E+6

The expected intensities in Table 1 promise a statistical error of about 10% in the measurement of the low intensity 607 keV in ^{34}Si and the corresponding branching ratio, depending also on the gamma spectrum background conditions.

The beta-decay intensities in 1^+ isomer decay, relative to the intensity of the 0_2^+ feeding in ^{34}Si, will be obtained also with low statistical error. If a state is feed both from the isomer and the g.s., as in the case of 2+ state described in Table 1., the subtraction of g.s. contribution will be done based on beta-times curves fit and on the intensities measured in previous ISOLDE experiment [13] when the 1^{+} isomer population was very low.

Determination of all the above quantities does not require the normalization, which is the number of decaying ^{34}Mg, ^{34}Al$_{g.s.}$ and ^{34}Al^{m} nuclei. Given the complex filiation scheme shown in Figure 4, the normalization is not a simple task. It is based on the knowledge of absolute intensities of gamma rays mentioned in Figure 4. Beam contamination with isobars could be at the level of 10% and could disturb the procedure. Therefore we propose that part of the experiment to profit from beam purification provided by LIST. The counting rates estimates for most relevant transitions are presented in Table 2, supposing 2 seconds measuring periods. Obviously, these estimates are giving only a rough expectation, based on the assumed branching ratio. We notice that main difficulties are due to ^{32,33}Al that can be hardly separated, leaving an uncertainty in ^{33}Si population from ^{34}Al^{m} decay of interest. However, reasonable limits are expected to be possible to be set, allowing for meaningful comparison of absolute intensities and *log ft* values with theoretical predictions.

Special attention will be given to acquisition dead-time correction known that, due to the very small half-times involved, the events are distributed highly non-uniform. The beta decay rate has a maximum of about 10 kHz. In order to minimize the dead-time, a digital acquisition will be used (using buffered mode for each channel and imposing the transfer of the buffers just before the arrival of next ions bunch).

Table 2. Count rate estimations of main gamma transition of daughter nuclei following ^{34}Mg decay in LIST mode (30 time reduction factor in ^{34}Mg intensity) and 2 s acquisition time per ions bunch.

Nu-clide	T1/2 (ms)	Population (events/sec)	Pn/P2n (%)	Gamma (keV)	Absolute Intensity (%)	Detection efficiency (%)	Count rate (events/day)
^{34}Mg	20±10	10	40?/10?				1E6
^{34}Al$_{g.s.}$	54.4±.5	2	74/0	124	28[a]	5	2.5E3
^{34}Al^{m}	26±1	3	75/0				
^{33}Al	41.7±.2	4	91.5/8.5	1941	2.5[b]	0.75	7.5E1
^{32}Al	33.0±.2	1	0/0	1941 3042	12[c] 4.3[c]	0.75 0.5	9E1 2E1
^{34}Si	2770 ±20	3.75	0/0	429 1607	30[d] 20[d]	3 1	1.4E3 3E2
^{33}Si	6110 ±21	4.95	0/0	1847 416	75[d] 3.5[d]	1 3	7.4E2 2E1
^{32}Si	153 y	1.3	0/0	-	-	-	-

a) [13]
b) A. C. Morton et al., Phys. Lett. B 544, 274 (2002)
c) P. M. Endt & R. B. Firestone, Nucl. Phys. A 633, 1 (1998)
d) S. Pietri, These de l'Universite de Caen, 2003.

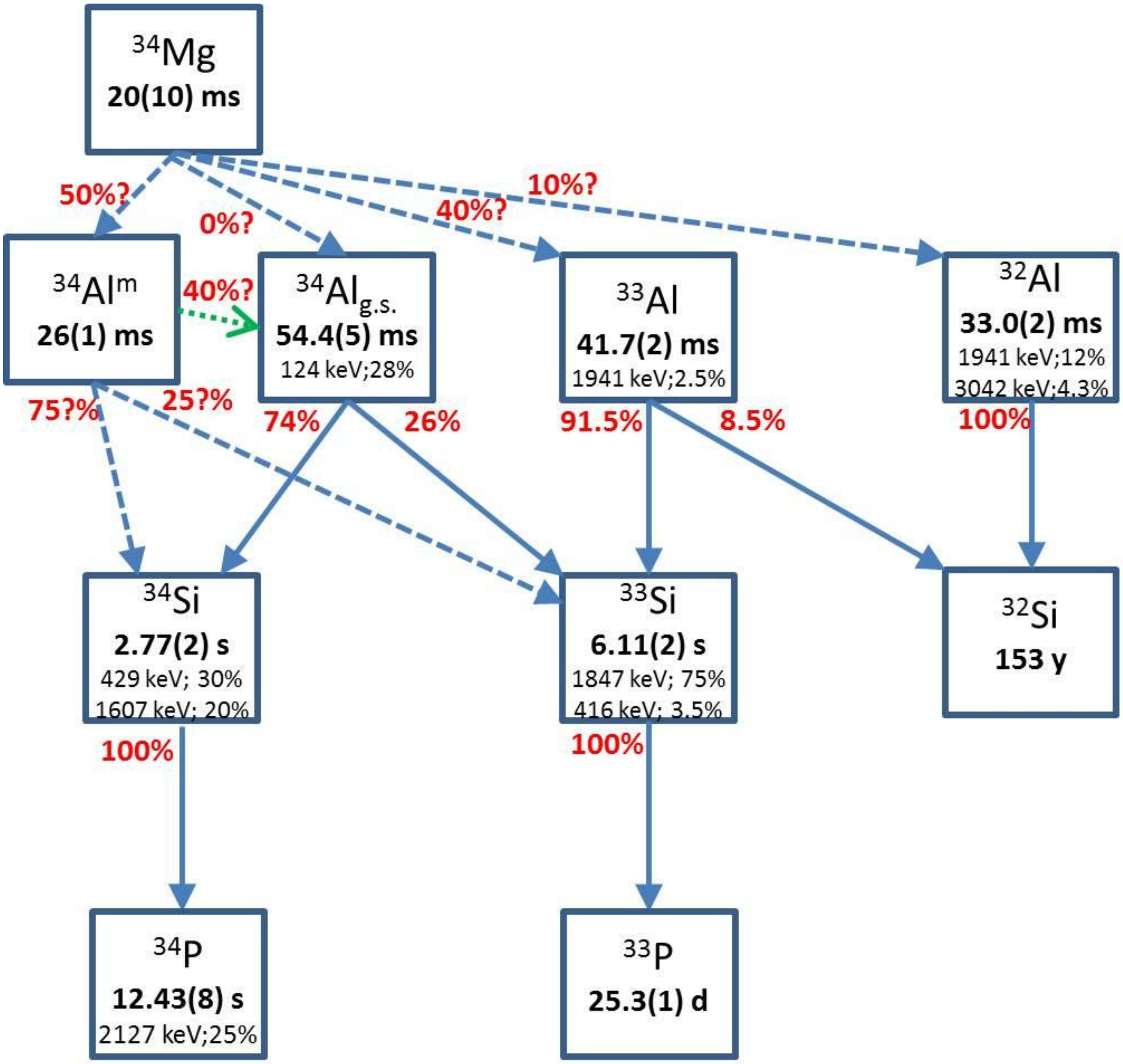

Figure 4. The dash line arrows represent beta or beta-n decay of unknown intensity. The full lines arrows are known decays, having mentioned energy and absolute intensity of the gamma transition used for normalisation. The green dotted arrow represents the 1+ isomer de-excitation to ground state.

Summary of requested shifts:

We requested **21 shifts** (7 days) split as follows:

3 shifts for beam and electronics tuning

12 shifts for the main part of the experiment: ^{34}Mg at maximum yield

6 shifts for ^{34}Mg using LIST

References:

[1] F.Rotaru et al., Colloque GANIL 2011; S. Grevy et al., ARIS 2011; to be published.
[2] C. Thibault et al., Phys. Rev. C12, 644(1975).
[3] E. Warburton et al., Phys. Rev. C 41, 1147 (1990)
[4] K.Yoneda et al., Phys. Lett. B 499, 233 (2001).
[5] H. Iwasaki et al., Phys. Lett. B 522, 227 (2001).
[6] J.A. Church et al., Phys. ReV. C**72,** 054320 (2005).
[7] M. Langevin et al., Nucl. Phys. A414,151(1984).
[8] V. Tripathi et al., Phys. Rev. Lett. 101, 142504 (2008).
[9] B.V. Pritychenko et al., Phys.Rev. C63, 047308 (2001).
[10] M. Gelin, PhD thesis, Université de Caen, 2007, GANIL T 07 02, online: http://tel.archives-ouvertes.fr/docs/00/19/30/46/PDF/T_gelin.pdf
[11] P.Himpe et al., Phys.Lett. B 658, 203 (2008).
[12] P. Baumman et al., Phys.Lett. B 228, 458 (1989).
[13] S. Numella et al., Phys.Rev. C63, 044316 (2001).
[14]R.W. Ibbotson et al., Phys.Rev.Lett. 80, 2081 (1998).
[15] L. K. Fifield et al., Nucl. Phys. A 440, 531-542 (1985).
[16] R. G. T. Zegers et al., Phys. Rev. Lett. 104, 212504 (2010).
[17] U. Koester et al., Nucl. Instrum. Meth. B 204, 347 (2003).

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 equipment	Availability	Design and manufacturing
ISOLDE fast-tape station	☒ Existing	☐ To be used without any modification ☒ To be modified: only implantation vacuum chamber
Standard radiation detectors and electronics	☒ Existing	☒ To be used without any modification ☐ To be modified
	☒ New	☒ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

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 hazads:

Hazards	*ISOLDE fast-tape station*	*Standard radiation detectors and electronics*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	Standard ISOLDE Vacuum		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid		NL2 for 4 Ge detectors, total Dewar volum: 30 l	
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]	max. 4 kV for Ge detectors, [current][A]	
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	Plastic tape		
Beam particle type (e, p, ions,	34Mg		

etc)			
Beam intensity	300 pps		
Beam energy	<100 keV		
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:		☐	
• Open source		☐	
• Sealed source		☒ [ISO standard]	
• Isotope		60Co, 137Cs, 152Eu	
• Activity		<10 microCi	
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• 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)*