Heavy Ion Accelerator Symposium 2019

Book of Abstracts and Program

Contents

Heavy Ion Accelerator Symposium 2019 Schedule

	Monday 9-Sep		Tuesday 10-Sep		Wednesday 11-Sep		Thursday 12-Sep		Friday 13-Sep
8:30	Registration								
	Opening chair: T. Senden		S5 chair: D. Fink		S9 chair: M. Dasgupta		S12 chair: B.B. Back		S16 chair: A. Gargano
9:30	Welcome to Country W. Bell	9:00	W. Kutschera	9:00	B.B. Back	9:00	K. Sekizawa	9:00	H. Watanabe
9:40	Welcome/Opening: K. Nugent	9:30	E. Prasad	9:30	R. Dressler	9:30	R. Golser	9:30	P. Collon
	S1 chair: J.M. Allmond	9:50	R. Banik	9:50	M. Caamaño Fresco	10:00	P. Papadakis (MARA)	10:00	J.T.H. Dowie
10:00	A.E. Stuchbery	10:10	P. Papadakis (^{188}Pb)	10:10	S. Pavetich	10:20	D. Robertson	10:20	Tea break
10:30	J.L. Wood	10:30	Tea break	10:30	Tea break	10:40	S. Merchel		S17 chair: A. Wallner
11:00	Tea break		S6 chair: F.G. Kondev		S10 chair: H. Watanabe	11:00	Tea break	11:00	A. Arazi
	S2 chair: S. Courtin	11:00	E. Ideguchi	11:00	F.G. Kondev		S13 chair: A.M. Smith	11:20	G.J. Lane
11:30	K.J. Cook	11:30	T. Tanaka	11:30	N. Grover	11:30	M. Paul	11:50	Closing
12:00	C. Müller-Gatermann	11:50	G. Savard	11:50	T.K. Eriksen	12:00	R. Lozeva	12:15	Lunch
12:20	M. Martschini	12:10	D. Koll	12:10	M. Schiffer (^{14}C)	12:30	B.J. Coombes	13:00	Departure
12:40	Lunch	12:30	Lunch/Photo	12:30	Lunch	12:50	Lunch		
	S3 chair: P. Collon		S7 chair: M.A.C. Hotchkis		S11 chair: M. Paul		S14 chair: T. Kibédi		
14:00	S. Antić	14:00	S. Courtin	14:00	A.M. Smith	14:00	A.J. Krasznahorkay		
14:30	S. Herb	14:30	K.M. Wilcken	14:30	S.W. Yates	14:30	G. Benzoni		
14:50	J. Gerl	14:50	Z. Slavkovská	15:00	B.M.A. Swinton-Bland	15:00	M.A. Stoyer		
15:10	E.A. Maugeri	15:10	B.P. McCormick	15:20	M.A.C. Hotchkis	15:20	Tea break		
15:30	Tea break	15:30	Tea break	15:40	Tea break		S15 chair: S.W. Yates		
	S4 chair: R. Golser		S8 chair: A.E. Stuchbery		Break out discussion(s)	16:00	A. Gargano		
16:00	D. Fink	16:00	J.M. Allmond			16:30	K. Stübner		
16:30	T.J. Gray	16:30	S.M. Mullins			16:50	P.D. Stevenson		
16:50	L.T. Bezzina	16:50	M. Schiffer (NWM)			17:10	M.S.M. Gerathy		
17:10	J. Stuchbery	17:10	B. Tee						
17:30	*Walk to Nuclear Physics*								
18:00	Welcome Reception Nuclear Physics			18:00	Symposium Dinner University House				Invited Presentation (25+5 min)
				19:30	L.L. Riedinger				Regular Presentation (15+5 min)

Registration and all lunch and tea breaks will be held in the foyer of the Hedley Bull Centre, just outside the lecture theatre. The welcome reception will be held at the Department of Nuclear Physics, which is a ~5-10 min walk from the Hedley Bull Centre. The symposium dinner will be held at University House, across the road from the Hedley Bull Centre.

Foreword

Dear HIAS 2019 Participants,

We are very glad to welcome you to Canberra for HIAS 2019, the seventh in the series of Heavy Ion Accelerator Symposia on Fundamental and Applied Science.

These symposia were first instituted 2012 by the Department of Nuclear Physics at the Australian National University. This year the symposium has an international focus with the following research topics

- Nuclear Structure and Nuclear Data
- Accelerator Mass Spectrometry Applications
- Nuclear Astrophysics
- Nuclear Reactions
- New Instrumentation for Nuclear Science and Applications

We are delighted to have received a strong response with more than 80 participants attending the Symposium. The contributions constitute a diverse program with a wide range of topics.

We gratefully acknowledge our sponsors Buckley Systems, Scitek Technologies for Science, the Research School of Physics and NCRIS. We thank Stefan Pavetich for taking on the time-consuming task of compiling this abstract booklet, Steve Tims for setting up the HIAS website and Petra Rickman for her outstanding role conference secretary.

Details about Wi-Fi access can be found on the inside cover of this book. The conference proceedings will be published in the EPJ Web of Conferences, referenced in SCOPUS and Web of Science, and freely available on the web.

September brings spring to Canberra and we hope for good weather and lively discussions that bride different research areas during this week. We wish you a productive and enjoyable time at the Symposium.

Tibor Kibédi, Anton Wallner
Co-Chairs, organising committee

Contact Information

E-mail: hias@anu.edu.au
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We strongly encourage all presenters to contribute to the HIAS 2019 conference proceedings. These will be published open source in electronic form as a regular volume of the journal EPJ Web of Conferences (see Vol 123 for the HIAS 2015 conference proceedings). Contributions will be peer-reviewed to assess their suitability for publication.

The Proceedings Guidelines for authors preparing manuscripts are available on the conference website. Contributions should be prepared using the LaTeX (preferred) or Word templates provided. Please note that the deadline for submission of contributions is Friday 1st of November 2019. Submissions should be emailed to the conference secretary at hias@physics.anu.edu.au.

You should already have signed the appropriate copyright permissions form at the registration desk. If not, please contact a member of the local organising committee.

Acknowledgements

The organisers are grateful for the support of the Australian National University and the National Collaborative Research Infrastructure Strategy (NCRIS) for providing administrative and financial support. We are also grateful for support from the Australian Institute of Nuclear Science and Engineering (AINSE) that provided student travel grants.

The organisers gratefuly aknowledge the support of the following sponsors:


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HIAS 2019 Program

Registration and all lunch and tea breaks will be held in the foyer of the Hedley Bull Centre, just outside the lecture theatre. The welcome reception will be held at the Department of Nuclear Physics, which is a 5-10 min walk from the Hedley Bull Centre. The symposium dinner will be held at University House, across the road from the Hedley Bull Centre.

Monday, 9th September

08:30 -- 09:30	**Registration**		
09:30 -- 10:00	**Opening session**	**Chair: T. Senden**	
09:30 W. Bell	*Traditional Welcome to Country*		
09:40 T. Kibédi, A. Wallner	*Welcome*		
K. Nugent (DVC-R)	*Conference Opening*		
10:00 -- 11:00	**Session 1**	**Chair: J.M. Allmond**	
10:00 A. E. Stuchbery	*The Heavy Ion Accelerator Facility: Research Achievements and Aspirations*		p69
10:30 J.L. Wood	*Universal, exclusive role of seniority and shape coexistence at closed shells*		p77
11:00 -- 11:30	**Morning Tea**		
11:30 -- 12:40	**Session 2**	**Chair: S. Courtin**	
11:30 K.J. Cook	*Unravelling the mechanisms for suppression of complete fusion in reactions of* ^{7}Li		p26
12:00 C. Müller-Gatermann	*Shape coexistence in the neutron-deficient nuclei near Z=82*		p52
12:20 M. Martschini	*Ion-Laser InterAction Mass Spectrometry and the quest for AMS of* ^{182}Hf		p48
12:40 -- 14:00	**Lunch**		

14:00 -- 15:30	**Session 3**	**Chair: P. Collon**	
14:00 S. Antić	*Neutron stars from crust to core with quark-meson coupling model*		p18
14:30 S. Herb	*The status of the new AMS device for medium mass isotopes at the Cologne University*		p39
14:50 J. Gerl	*Status of the FAIR project*		p35
15:10 E.A. Maugeri	*Production of exotic radionuclides targets for nuclear astrophysics experiments*		p49
15:30 -- 16:00	**Afternoon Tea**		
16:00 -- 17:30	**Session 4**	**Chair: R. Golser**	
16:00 D. Fink	*Constraining the age of Aboriginal rock art using cosmogenic ^{10}Be and ^{26}Al dating of rock shelter collapse in the Kimberley region, Australia.*		p32
16:30 T.J. Gray	*Enhanced collectivity of neutron-rich ^{129}Sb beyond the particle-core coupling scheme*		p37
16:50 L.T. Bezzina	*Examining equilibration in heavy ion fusion using precision cross section measurements of the compound nucleus ^{220}Th*		p23
17:10 J. Stuchbery	*The ANU Heavy Ion Accelerator Facility External Beam Line*		p70
17:30	**Walk to Department of Nuclear Physics**		
18:00	**Welcome reception at the Department of Nuclear Physics**		

Tuesday, 10th September

09:00 -- 10:30	**Session 5**	**Chair: D. Fink**	
09:00 W. Kutschera	*The movements of Alpine glaciers throughout the last 10,000 years as sensitive proxies of temperature and climate changes*		p45
09:30 E. Prasad	*Effect of N/Z and dissipation in the fission of* $^{212,214,216}Ra$ *nuclei via neutron multiplicity measurements*		p58
09:50 R. Banik	*Exploring the structure of Xe isotopes in A∼130 region: Single particle and Collective excitations*		p21
10:10 P. Papadakis	*A study of the excited* 0^{+} *states in* ^{188}Pb		p54
10:30 -- 11:00	**Morning Tea**		
11:00 -- 12:30	**Session 6**	**Chair: F.G. Kondev**	
11:00 E. Ideguchi	*Shape coexistence in mass 40 region studied via E0 and gamma transitions*		p41
11:30 T. Tanaka	*Study of Barrier Distributions from Quasielastic Scattering Cross Sections towards Superheavy Nuclei Synthesis*		p73
11:50 G. Savard	*Constraining the conditions for r-process nucleosynthesis via nuclear measurements at CARIBU*		p61
12:10 D. Koll	*Evidence for Recent Interstellar* ^{60}Fe *on Earth*		p42
12:30 -- 14:00	**Lunch & Conference Photo**		
14:00 -- 15:30	**Session 7**	**Chair: M.A.C. Hotchkis**	
14:00 S. Courtin	*News on the Carbon Burning at Astrophysical Energies*		p28
14:30 K.M. Wilcken	*Curious case of* ^{26}Al *accelerator mass spectrometry*		p76
14:50 Z. Slavkovská	*Combining activation technique and AMS for s-process measurements*		p65
15:10 B.P. McCormick	*Modelling hyperfine interactions to perform picosecond-lifetime Nuclear g-factor Measurements*		p50
15:30 -- 16:00	**Afternoon Tea**		

16:00 -- 17:30	**Session 8**	**Chair: A.E. Stuchbery**	
16:00 J.M. Allmond	*Coulomb-Excitation and Beta-Decay Studies of* ^{104,106}*Mo at CARIBU with the New EBIS*		p17
16:30 S.M. Mullins	*Sub-Saharan Climatic Catastrophe Forewarned by AMS*		p53
16:50 M. Schiffer	*Ion Beam Techniques for Nuclear Waste Management*		p63
17:10 B. Tee	*Penetration effect on internal conversion for the 35.5 keV M1 l-forbidden transition in* ^{125}*Te following the EC-decay of* ^{125}*I*		p74

Wednesday 11th September

09:00 -- 10:30	**Session 9**	**Chair: M. Dasgupta**	
09:00 B.B. Back	*Opportunities for detailed fission studies using light, charged particle reactions*		p20
09:30 R. Dressler	*Measurement of the* $^{53}Mn(n,\gamma)$ *cross-section at stellar energies*		p30
09:50 M. Caamaño Fresco	*Structure of superheavy* ^{7}H		p24
10:10 S. Pavetich	*Single atom counting of* ^{55}Fe *for explosive stellar nucleosynthesis studies*		p57
10:30 -- 11:00	**Morning Tea**		
11:00 -- 12:30	**Session 10**	**Chair: H. Watanabe**	
11:00 F.G. Kondev	*Masses and Beta-Decay Spectroscopy of Neutron-Rich Nuclei: Isomers and Sub-shell Gaps with Large Deformation*		p43
11:30 N. Grover	*Fragmentation analysis of* $^{88}Mo^{*}$ *compound nucleus in view of different decay mechanisms*		p38
11:50 T.K. Eriksen	*Improved precision on the experimental E0 decay branching ratio of the Hoyle state*		p31
12:10 M. Schiffer	*Measurement of small and ultra-small* ^{14}C *samples*		p62
12:30 -- 14:00	**Lunch**		
14:00 -- 15:40	**Session 11**	**Chair: M. Paul**	
14:00 A.M. Smith	*Cosmogenic radionuclides as signatures of past Solar storm events*		p66
14:30 S.W. Yates	*Relevance of the Nuclear Structure of the Stable Ge Isotopes to the Neutrinoless Double-Beta Decay of* ^{76}Ge		p78
15:00 B.M.A. Swinton-Bland	*Systematic Study of Quasifission in* ^{48}Ca*-Induced Reactions*		p72
15:20 M.A.C. Hotchkis	*Achieving the ultimate sensitivity in Accelerator Mass Spectrometry of high mass isotopes*		p40
15:40 -- 16:00	**Afternoon Tea**		
16:00 -- 18:00	**Break out discussion**		

18:00		**Conference dinner at University House**	
19:30	L.L. Riedinger	*Changing Picture of Energy Generation in Australia and the U.S.*	p59

Thursday, 12th September

09:00 -- 11:00	**Session 12**	**Chair: B.B. Back**	
09:00 K. Sekizawa	*Time-Dependent Hartree-Fock Theory and Its Extensions for the Superheavy Element Synthesis*		p64
09:30 R. Golser	*Ion Laser Interaction AMS: Why poor gas gives pure beams*		p36
10:00 P. Papadakis	*The MARA Low-Energy Branch – towards day 1*		p55
10:20 D. Robertson	*Recent and Future Underground Low-Energy Nuclear Astrophysics Experiments*		p60
10:40 S. Merchel	*Sample preparation for AMS astrophysics projects – Size does (not) matter*		p51
11:00 -- 11:30	**Morning Tea**		
11:30 -- 12:50	**Session 13**	**Chair: A.M. Smith**	
11:30 M. Paul	*Study of Astrophysical s-Process Neutron Capture Reactions at the High-Intensity SARAF-LiLiT Neutron Source*		p56
12:00 R. Lozeva	*Beyond* ^{132}Sn		p47
12:30 B.J. Coombes	*Emergence of nuclear collectivity through* 4_1^+ *g factors in* $^{124-130}Te$		p27
12:50 -- 14:00	**Lunch**		
14:00 -- 15:20	**Session 14**	**Chair: T. Kibédi**	
14:00 A.J. Krasznahorkay	*Confirmation the existence of the X17 particle*		p44
14:30 G. Benzoni	*Shape Evolution in Ni isotopic chain*		p22
15:00 M.A. Stoyer	*Fission Product Yield Measurements from Neutron Induced Fission of* $^{235,238}U$ *and* ^{239}Pu		p68
15:20 -- 16:00	**Afternoon Tea**		

16:00 -- 17:30	Session 15	Chair: S.W. Yates
16:00 A. Gargano	*Realistic shell model and nuclei around* ^{132}Sn	p33
16:30 K. Stübner	*AMS measurements of cosmogenic nuclide concentrations resolve mountain landscape evolution and the glacial history in the Pamir, Central Asia*	p71
16:50 P.D. Stevenson	*Role of the surface energy in heavy-ion collisions*	p67
17:10 M.S.M. Gerathy	*Gamma-electron spectroscopy with Solenogam: Isomeric Decay in* ^{145}Sm	p34

Friday 13th September

09:00 -- 10:20	**Session 16**	**Chair: A. Gargano**	
09:00 H. Watanabe	*Shell evolution and isomers below ^{132}Sn: Spectroscopy of neutron-rich $_{46}Pd$ and $_{47}Ag$ isotopes*		p75
09:30 P. Collon	*Low-energy injection and AMS beamline upgrade at the NSL and ^{36}Cl production in X-wind model revisited*		p25
10:00 J.T.H. Dowie	*Exploring shape coexistence between doubly magic ^{40}Ca and ^{56}Ni through pair-conversion spectroscopy*		p29
10:20 -- 11:00	**Morning Tea**		
11:00 -- 12:15	**Session 17**	**Chair: A. Wallner**	
11:00 A. Arazi	*Iodine isotopes in rainwater from Argentina: First ^{129}I deposition rates reported for the Southern Hemisphere*		p19
11:20 G.J. Lane	*SABRE and the Stawell Underground Physics Laboratory: Dark Matter Research at the Australian National University*		p46
11:50 A. Wallner, T. Kibédi	*Closing*		
12:15 -- 13:00	**Lunch**		
13:00	**Departure**		

Abstracts

Coulomb-Excitation and Beta-Decay Studies of ^{104,106}Mo at CARIBU with the New EBIS

J.M. Allmond[1]
[1] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831*

Collective shape degrees of freedom have been a major direction in the study of the nuclear finite many-body problem for over 50 years. There is widespread evidence for quadrupole deformations, primarily of large prolate spheroidal deformation with axially symmetric rotor degrees of freedom. This naturally leads to the question of whether or not axially asymmetric rotor degrees of freedom are exhibited by any nuclei, with the implication of triaxial shapes. With respect to best cases for observation of triaxial shapes near the ground state, two regions stand out. The first is the Os-Pt region and the second is the neutron-rich Mo-Ru region, where low-energy 2_2^+ states are consistent with such an interpretation. Furthermore, the neutron-rich Mo-Ru region is expected to undergo a relatively rare instance of prolate-to-oblate shape evolution. Recent results from Coulomb-excitation and beta-decay studies of neutron-rich Mo-Ru isotopes will be presented. These experiments were conducted at the CARIBU-ATLAS facility of ANL using GRETINA-CHICO2. A survey of the equipment, techniques, and results will be presented. In addition, a comparison of ^{106}Mo Coulomb-excitation data with the old ECR and new EBIS ion sources will be highlighted.

*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics.

Neutron stars from crust to core with quark-meson coupling model

S. Antic,[1] and A.W. Thomas[1]
[1]*CSSM, Department of Physics, University of Adelaide SA 5005 Australia*

Recent years continue to be an exciting time for the neutron star physics, providing many new observations and insights to these natural 'laboratories' of cold dense matter. To describe them, we are introducing the quark-meson coupling model that stands out among many others on the market with the natural inclusion of hyperons as dense matter building blocks and the small number of parameters necessary to obtain the nuclear matter equation of state [1]. The latest advances of QMC model and its application to the neutron star physics will be presented, starting from their outer crust nuclei content and moving inwards up to the high core densities of todays heaviest known neutron stars [2].

[1] P. A. M Guichon, J. Stone, A.W. Thomas, Prog. Part. Nucl. Phys. **100**, 262-297 (2018).

[2] T. Motta, A.M. Kalaitzis, S. Antić, P. A. M Guichon, J. Stone, A.W. Thomas, arXiv:1904.03794 (2019).

Iodine isotopes in rainwater from Argentina: First ^{129}I deposition rates reported for the Southern Hemisphere

A.E. Negri,[1,2] A. Arazi,[2,3] J. Fernández Niello,[1,2,3] D. Martinez Heimann,[1,2] M. Paparas,[4]
A. Wallner,[5] M. Fröhlich,[5] S. Pavetich,[5] S.G. Tims,[5] L.K. Fifield,[5] and M.E. Barlasina[4]
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Iodine is a very mobile element which follows a complex geochemical cycle, including evaporation, dry and wet deposition, and transportation by wind and ocean currents. The interchange processes in this cycle can be experimentally traced by the long-lived radionuclide ^{129}I, which is produced by natural and now dominantly by anthropogenic processes. For using ^{129}I as a global tracer, in particular, to assess the interchange between Northern and Southern Hemispheres, comprehensive worldwide data are necessary. While plenty of ^{129}I concentration measurements were performed in the Northern Hemisphere, scarce data are available for the Southern one. In this work, concentration of iodine isotopes, deposition of ^{129}I and ^{129}I/^{127}I ratios in rainwater samples from several stations across Argentina were analyzed aiming to assess current distribution patterns and potential sources of atmospheric iodine in the region. The gathered data imply a higher than expected ^{129}I deposition flux, indicating the existence of another source besides natural contribution and recycling from nuclear weapons fallout. Nuclear fuel reprocessing plants in western Europe look as candidates as only a minute fraction of their emissions entering the austral hemisphere would give account of the ^{129}I excess found in this work. Moreover, a four-year (2011-2014) monthly sampled rainwater time series from Buenos Aires was studied. This set presents high isotopic ratio variability, suggesting the mix of material from sources with different isotopic mark in the region. Retrospective monthly ^{129}I deposition flux in Buenos Aires after French nuclear tests during 1960s and 1970s in Polynesia are also reported.

Opportunities for detailed fission studies using light, charged particle reactions

B.B. Back[1]
[1]*Argonne National Laboratory, Lemont, Illinois 60439, USA*

Since its discovery in 1939, the nuclear fission process provides much insight into the behavior of nuclei under many different conditions. As part of the nuclear chain reaction, the fission process has had a profound impact on modern society and it has consequently attracted much attention to the field of nuclear physics.

In this talk, I will argue that the time is ripe for a resumption of studies of the fission process induced by light, charged particle reactions. Although nuclear fission can be induced in heavy nuclei by several means, in some cases by forming highly excited nuclei by heavy-ion fusion or multi-nucleon transfer reactions, these methods suffer from the complication that fission can occur at several points during the decay chain thus mixing up contributions from different excitation energies. Using instead light charged particle reactions to excite the nuclei in question, the precise excitation energy from which fission takes place, can be determined. In fact, a number of such studies we carried out previously, and a first set of results on fission barrier heights, mass, energy and angular distributions were obtained.

Applying detection techniques developed over the last decades, will allow researchers to obtain detailed, high-quality data from which to probe and refine our present understanding of the process. In the meantime, more fundamental theories have been developed that will allow for a deeper understanding of the fission process. Based on these observations, I suggest that substantial advances in the study of this process can be achieved by using simple light, charged-particle reactions.

This material is based on work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract number DEAC02-06CH11357.

Exploring the structure of Xe isotopes in A~130 region: Single particle and Collective excitations

R. Banik[1,2] *et. al.*
[1]*Variable Energy Cyclotron Centre, Kolkata, India*
[2]*Homi Bhabha National Institute, Mumbai, India*

The existence of variety of nuclear shapes and their coexistences are the results of the complicated interplay between the single-particle and the collective motions of the nucleus. The structures of nuclei around the doubly magic shell closure ^{132}Sn (N = 82 and Z = 50) are of contemporary interest to obtain the information on both single particle and collective modes of excitations. Isotopes with a few proton particles and neutron holes with respect to the shell closure give us the unique opportunity to investigate the low lying single particle level structures, which in turn helps us to understand the effective nucleon-nucleon shell model residual interactions. The Xe (Z=54) nuclei in A~130 transitional region are important links between the spherical and deformed shapes. Coupling of valance nucleons in high-j orbitals in the high-spin regime forms a variety of band structures. In odd-A Xe nuclei, the valence neutron in high-j orbital is responsible in generating different band structures. ^{125}Xe is known to have band structures based on prolate deformation [1], whereas ^{127,129}Xe are reported to have significant triaxiality [2, 3]. But data on the next Xe isotopes are very limited [4, 5]. In this mass region, the even mass Xe isotopes are potential candidates for investigation of E(5) symmetry breaking since the experimental $R_{4/2}$ ratios are very close to the theoretical predicted values [6,7].

In the present work, excited levels of ^{130,131}Xe were populated via the reaction ^{130}Te (α, xn) ^{130,131}Xe, at a beam energy of 38 MeV, delivered from the K-130 cyclotron at Variable Energy Cyclotron centre (VECC), Kolkata. The Indian National Gamma Array (INGA) setup at VECC, consisting of seven Compton suppressed Clover detectors, were used for the detection of γ rays. Digital data acquisition system consisting of PIXIE-16 digitizer modules was used to acquire the time stamped LIST mode data [8].

In the present work, 67 new transitions have been placed in the level scheme of ^{131}Xe. The Yrast negative parity band in ^{131}Xe is seen above the band crossing frequency and the possible signature partner of this band is also observed. Presence of several band structures is also established from the present work. The new results are explained in terms of large scale shell model (using NUSHELLX) and TRS calculations. New transitions are identified at lower spin region in ^{130}Xe which carries the information about E(5) symmetry breaking. Details of this work will be presented at the conference.

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Shape Evolution in Ni isotopic chain

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Shape-transitional phenomena are indicators of alterations in the normal-order configuration of protons and neutrons. For exotic nuclei, they may prelude the discovery of new nuclear regions in which the ground states are dominated by deformed intruder configurations, the so-called islands of inversion. Shape transitions can also take place with excitation energy or angular momentum, leading to the coexistence of different shapes within the same nucleus [1].

The nuclear region around ^{78}Ni, close to the classic shell closures with Z=28 and N=50, has attracted great attention in recent years in particular addressing the evolution of nuclear shapes. Going from the more stable to the very exotic systems a variety of phenomena are encountered, starting from the existence of shape isomerisms found in ^{66}Ni [2] to coexistence of shapes, measured in the heavier systems $^{68-72}$Ni [3, 4].

The Ni isotopic chain has been investigated by the Milano gamma-spectroscopy group exploiting several mechanisms, starting from sub-barrier fusion to β decay, in campaigns performed in world-leading facilities.

An overview of recent results in the Ni isotopic chain will be reported in this talk.

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Examining equilibration in heavy ion fusion using precision cross section measurements of the compound nucleus ^{220}Th

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Heavy-ion fusion is a complex, many-body quantum process, whereby two separate nuclei merge to form a single, compact compound nucleus. It is intrinsically dissipative, requiring the kinetic energy of the collision to be dispersed into a multitude of internal nucleonic excitations. Existing models of fusion, accounting for the coherent superposition of collective excited states [1], have been quite successful in predicting the outcome of fusion at energies near and below the fusion barrier. Crucially, however, these models do not explicitly treat the progression of the system from a fully coherent quantum state to the thermalised, compact compound nucleus. As a consequence, predictions of fusion cross sections at above barrier energies with these models may disagree with experiment by up to a factor of 2 [2].

Determining the variables which control this thermalisation is a key step in understanding the progression towards a fully energy-dissipated compound nucleus. One variable thought to be important is the amount of nuclear matter overlap at barrier radius. This matter overlap is controlled by the entrance channel charge product, Z_pZ_t. Experimental studies of the same compound nucleus formed using differing Z_pZ_t will reveal how this variable influences compound nucleus formation.

This talk will outline the experimental program designed to measure the outcomes following compound nucleus formation: evaporation residue (ER) formation and fusion-fission. Measuring the cross section of compound nucleus decay modes will then allow quantification of other collision outcomes that are otherwise indistinguishable from the fusion-fission mode, in particular, quasi-fission, which is known to suppress fusion. A presentation of the development of the method to extract high-precision ER cross sections will be included, along with benchmarking reactions and initial data from the new 8T version of the SOLITAIRE experiment [3]. Preliminary fission cross sections measured with the ANU CUBE fission spectrometer will also be presented.

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Structure of superheavy ^{7}H

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While the foundations of our current knowledge in nuclear physics are based on the properties of stable isotopes, the new phenomena that appear as we move away from stability, in systems with unbalanced neutron–to–proton ratios, are key to improve the nuclear models and thus our understanding of nuclear matter. In this respect, the most extreme neutron–to–proton ratio is found in the ^{7}H resonance, the heaviest of the hydrogen isotopes and, so far, the last of the longest isotopic chain of nuclei outside the binding limits of the nuclear chart. The description of its basic properties, even its sheer existence, is still a challenge for current theoretical models and experimental efforts. Here we discuss the first measurement of the characteristics and structure of the ^{7}H ground state. These new and comprehensive experimental results, including the differential cross section, depict a low–lying, almost bound resonance with a relatively long half–life. The measured properties are consistent with a ^{3}H core surrounded by an extended dineutron condensate that decays through a unique four–neutron emission, showing the cohesive effect of neutron pairing within an almost–pure neutron environment. These properties are unique inputs and a stringent test for models dealing with extreme nuclear scenarios such as neutron condensates, the possible existence of a tetra–neutron system or the conditions of nuclear matter in the crust of neutron stars.”

Low-energy injection and AMS beamline upgrade at the NSL and ^{36}Cl production in X-wind model revisited

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In conjunction with the upgrade of the Nuclear Science Laboratory's (NSL) FN-tandem's low energy (LE) injection beamline in 2016-17, the AMS beamline was upgraded in 2018-19 and a Time-of-Flight section was added. In addition to the improved selectivity, the new system also provides off-axis Faraday cups for stable beam monitoring as well as sequential beam injection. The new capabilities greatly improve the precision of Accelerator Mass Spectrometry (AMS) measurements and the talk will present new results made with the system, in particular results associated with the production of ^{36}Cl for X-Wind models in the Early solar system.

In a previous measurement performed by Bowers et al. (2013) [1], the cross section of the ^{33}S(α,p)^{36}Cl reaction was studied using a combination of activation of a ^{4}He gas cell and analyzing the produced ^{36}Cl via AMS over an energy range of 0.7 – 2.42 MeV/A. The result of this measurement was a significantly higher yield of ^{36}Cl than usually predicted by Hauser-Feshbach cross section calculations [1]. A new experimental campaign in collaboration with PRIMELAB of Purdue University was started to confirm the production cross section of this reaction, which contributes significantly to the abundance of ^{36}Cl in the Early Solar System and is an important input in solar irradiation models [2].

In addition a new campaign to measure the ^{34}S(^{3}He,p)^{36}Cl production cross-section in the same energy range was recently performed at Notre Dame. Results of the ^{33}S(α,p)^{36}Cl re-measurements [3] as well as the new ^{34}S(^{3}He,p)^{36}Cl campaign will be presented.

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Unravelling the mechanisms for suppression of complete fusion in reactions of ^{7}Li

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A long-standing problem affecting the studies and uses of light weakly-bound nuclei is the observed suppression of above-barrier complete fusion (e.g. [1]) by $\sim$ 30% relative to calculations and to measurements for comparable well-bound systems. The mechanism for the suppression of complete fusion has long been thought to be due to projectile breakup prior to reaching the fusion barrier. However, recent work [2–5] has shown that the yields and characteristic timescales of breakup cannot explain the degree of fusion suppression. Therefore, an additional mechanism must be involved.

To investigate this mechanism, we performed comprehensive measurements of the energy and angles of singles and coincidence protons, deuterons, tritons and α-particles produced in above-barrier reactions of ^{7}Li + ^{209}Bi. By subtracting the double-differential cross-sections for α-particles produced in no-capture breakup from those of the inclusive prompt α-particles, we extract the double-differential cross-sections for α-particles unaccompanied by any other charged fragment. These unaccompanied α-particles are produced in the same reactions forming the polonium incomplete fusion product (whose presence is associated with complete fusion suppression).

We demonstrate that characteristics of these unaccompanied α-particles are inconsistent with the conventional picture of breakup of ^{7}Li followed by capture of a Z=1 fragment. We show that the measured distributions are in fact consistent with direct triton cluster transfer. Furthermore, coincidence measurements between projectile-like fragments and decay α-particles from the short-lived ground-state decay of ^{212}Po allows the first direct determination of their production mechanism, namely, triton transfer.

Crucially, our results [6] indicate that the suppression of complete fusion is primarily a consequence of innate clustering of weakly-bound nuclei, rather than of breakup [7].

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Emergence of nuclear collectivity through 4_1^+ g factors in $^{124-130}$Te

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The emergence of collectivity along isotopic chains gives essential information as to the degrees of freedom important in creating collectivity. Typically, the onset of collectivity has been studied through $E2$ observables which are not very sensitive to the underlying particle structure. The measurement of g factors allows the underlying single-particle structure to be sensitively probed. The 2^+, 4^+, and 6^+ states in the Te isotopes begin as $(\pi g_{7/2})^2$ states in the semi-magic ^{134}Te. As neutrons are removed below $N = 82$, the single particle nature of the low-lying states becomes more mixed and collective structures emerge. The objective of this work is to observe the origin of collective degrees of freedom by comparing experimental g factors to shell-model calculations.

Shell-model calculations of the even Te isotopes have predicted that along the isotopic chain the ratio of $g(4_1^+)/g(2_1^+)$ proceeds from $\sim$1 in the semi-magic ^{134}Te to $\sim$2 near the closed shell, before converging to the collective limit $g(2^+) \approx g(4^+) \approx 0.8Z/A$. (See e.g. the effective field theory calculations of Coello-Perez and Papenbrock for vibrational nuclei [1]). A similar pattern has been observed in $^{130-136}$Xe [2, 3]. Transient-field g-factor measurements have been performed using the ANU Hyperfine Spectrometer on separated even isotope $^{124-130}$Te targets to measure the 4_1^+ state g factors relative to the g factors of the 2_1^+ states.

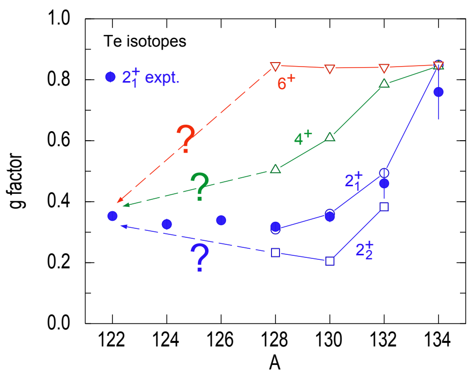

FIG. 1: Experimental g factors of the 2_1^+ states in $^{122-134}$Te. Shell-model g factors for $^{128-134}$Te are shown as hollow points.

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News on the Carbon Burning at Astrophysical Energies

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Fusion reactions play an essential role in understanding the energy production, the nucleosynthesis of chemical elements and the evolution of massive stars. Thus, the direct measurement of key fusion reactions at thermonuclear energies is of very high interest. The carbon burning in stars is essentially driven by the $^{12}C+^{12}C$ fusion reaction. This reaction is known to show prominent resonances at energies ranging from a few MeV/nucleon down to the sub-Coulomb regime, possibly due to molecular ^{12}C-^{12}C configurations in ^{24}Mg [1]. The persistence of such resonances down to the Gamow energy window is an interesting question. This reaction could also be subject to the fusion hindrance phenomenon which has been evidenced for medium mass nuclei and measured in numerous systems [2].

This contribution will discuss recent measurements performed in the $^{12}C+^{12}C$ system at deep sub-barrier energies using the newly developed STELLA apparatus associated with the UK FATIMA detectors for the exploration of fusion cross-sections of astrophysical interest [3]. Gamma-rays have been detected in an array of $LaBr_3$ detectors and protons and alpha particles were identified in double-sided silicon-strip detectors. A novel rotating target system has been developed able to sustain high intensity carbon beams delivered by the Andromede facility of the University Paris-Saclay and IPN-Orsay (France). The gamma-particle coincidence technique as well as nanosecond timing conditions have been used in the analysis in order to minimize background. This has allowed to obtain astrophysical S factors down to the Gamow window which will be presented and discussed in the frame of previous experimental results and theoretical calculations on the deep sub-barrier $^{12}C+^{12}C$ fusion reaction.

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Exploring shape coexistence between doubly magic ^{40}Ca and ^{56}Ni through pair-conversion spectroscopy

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The phenomenon of shape coexistence, whereby excited states of an atomic nucleus exhibit shapes that deviate dramatically from their ground states, appears to be ubiquitous across the nuclear landscape. Electric monopole (E0) transitions, the only possible decay paths between $J^{\pi} = 0^{+}$ states, provide a unique probe into nuclear structure. The E0 strength is large when there is a large change in the nuclear mean-square charge radius, and when there is strong mixing between states of different deformation. E0 transitions give us a probe to examine and understand shape coexistence [1, 2].

The region between ^{40}Ca and ^{56}Ni is virtually unexplored from the perspective of E0 transitions. Only the Ca isotopes and ^{54}Fe have been investigated [3]. Recent developments in the nuclear shell model allow for the calculation of the complete low-energy level structure and transition rates, including E0 transitions [4]. This region is then a perfect case to explore nuclear structure and shape coexistence through the lens of E0 transitions. In addition, the low-lying (<4 MeV) level structure of ^{50}Cr is not complete: there is a controversy over the position of the 0^{+} states in ^{50}Cr [5, 6]. In searching for a non-analog branch in the superallowed beta decay of ^{50}Mn, two 0^{+} states in ^{50}Cr at 3895.0(5) and 4733(5) keV were observed by Leach *et al.* [6]. We sought to confirm these 0^{+} states through the observation of their E0 transitions.

The 0^{+} states and E0 transitions in ^{40}Ca, ^{50,52,54}Cr, ^{54,56,58}Fe and ^{58,60,62}Ni were investigated with the Super-e pair spectrometer at the ANU [8, 9] using beams from the 14UD tandem accelerator. The Super-e pair spectrometer is a superconducting, magnetic-lens spectrometer for the measurement of conversion electrons and electron-positron pairs with excellent background suppression [7]. We will present the first pair spectra for ^{50,52,54}Cr, ^{54,56,58}Fe and the E0 transition strengths for these nuclei.

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Measurement of the ^{53}Mn (n, γ) cross-section at stellar energies

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^{53}Mn ($t_{1/2} \approx 3.7$ Ma) is expected to be one of the major short-lived radioisotopes produced during type II supernovae explosions [1, 2]. It can undergo further nuclear reactions due to its long half-life, which may influence the isotopic abundances of neighboring stable isotopes. Additionally, it can serve as a sensitive chronometer to date processes in the early solar system [3] and to determine the exposure time of terrestrial material to high energetic cosmic radiation [4].

We report here on the first measurement of the Maxwellian Averaged Cross-Section (MACS) of ^{53}Mn at stellar neutron energies performed at the Soreq Applied Research Accelerator Facility (SARAF) facility at the Soreq nuclear research center.

The target containing ~10^{18} atoms ^{53}Mn was prepared using a stock solution previously extracted and purified from activated accelerator waste in the course of the ERAWAST initiative [5] at PSI. The total number of ^{53}Mn atoms in the target was deduced from a retained sample via multi-collector ICP-MS measurements at PSI.

The activation of ^{53}Mn with neutrons of a quasi-Maxwellian spectrum of about 40 keV was performed using the Liquid-Lithium Target LiLiT) installation at the Soreq Applied Research Accelerator Facility (SARAF-) [6]. The ^{53}Mn target was encapsulated in an aluminum holder and introduced into a vacuum chamber in close proximity to the neutron entrance window immediately behind the liquid Lithum film.

The total accumulated neutron fluence was deduced from γ-measurements of co-activated gold foils mounted externally on the target holder and of natural cobalt added to the target material as an internal flux monitor. The ^{54}Mn, ^{60}Co and ^{198}Au activities were measured before and after the irradiation using high-resolution γ-spectroscopy.

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Improved precision on the experimental $E0$ decay branching ratio of the Hoyle state

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Stellar carbon synthesis occurs exclusively via the 3α process, in which three α particles fuse to form ^{12}C in the excited Hoyle state followed by electromagnetic decay to the ground state. The Hoyle state is energetically above the α threshold, and the rate of stellar carbon production depends directly on the radiative width of this state. The radiative width cannot be measured directly, and must instead be deduced by combining three separately measured quantities. One of these quantities is the $E0$ decay branching ratio of the Hoyle state, and the current $\approx 10\%$ uncertainty on the radiative width stems mainly from the uncertainty of this ratio. The rate of the 3α process is an important input parameter in astrophysical calculations on stellar evolution, and a high precision is imperative to constrain the possible outcomes of different astrophysical models. We have carried out a series of pair conversion measurements of the $E0$ and $E2$ transitions depopulating the Hoyle state and 2_1^+ state in ^{12}C, respectively, with the aim to deduce a new, more precise value on the $E0$ decay branching ratio. The excited states were populated by the ^{12}C(p,p') reaction at 10.5 MeV beam energy, and the pairs were detected with the electron-positron pair spectrometer, Super-e, at the Australian National University. The deduced branching ratio required knowledge on the proton population of the two states, as well as the alignment of the 2_1^+ state in the reaction. For this purpose, proton scattering and γ-ray angular distribution experiments were also performed. An averaged $E0$ branching ratio of $\Gamma_\pi^{E0}/\Gamma = 7.47(46)\cdot 10^{-6}$, with an uncertainty of 6%, was deduced. Based on a weighted average of previous literature values and the new result we recommend a value of $\Gamma_\pi^{E0}/\Gamma = 7.21(37)\cdot 10^{-6}$. The new recommended value on the $E0$ branching ratio is about 7% larger than the previous adopted value of $\Gamma_\pi^{E0}/\Gamma = 6.7(6)\cdot 10^{-6}$, and the uncertainty has been reduced from 9% to 5%. The experimental methods, results, and implications will be discussed in this presentation.

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Constraining the age of Aboriginal rock art using cosmogenic Be-10 and Al-26 dating of rock shelter collapse in the Kimberley region, Australia.

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The Kimberley region, northwest Australia, possesses an extensive and diverse collection of aboriginal rock art that potentially dates to more than 40,000 years ago. However, dating of such art using conventional techniques remains problematic. Here, we develop a new approach which makes use of the difference in production rates of in-situ 10Be and 26Al between intact rock walls and exposed surfaces of detached slabs from rock art shelters to constrain the age of Aboriginal rock-art. In the prevailing sandstone lithology of the Kimberley region, open cave-like rock shelters with cantilevered overhangs evolve by the collapse of unstable, partially rectangular, blocks weakened typically along joint-lines and fractures. On release, those slabs which extend outside the rock face perimeter will experience a higher production rate of cosmogenic 10Be and 26Al than the adjacent rock which remains intact within the shelter.

The dating of these freshly exposed slabs can help reconstruct rock-shelter formation and provide either maximum or minimum ages for the rock art within the shelter. At each site, both the upper-face of the newly exposed fallen slab and the counterpart intact rock surface on the ceiling need to be sampled at their exact matching-point to ensure that the initial pre-release cosmogenic nuclide concentration on slab and ceiling are identical.

The calculation of the timing of the event of slab release is strongly dependent on the local production rate, the new shielding of the slab surface and the post-production that continues on the ceiling sample at the matching point. The horizon, ceiling and slab shielding are estimated by modelling the distribution of neutron and muon trajectories in the irregular shaped rock-shelter and slab using 3D photogrammetric reconstruction from drone flights and a MATLAB code (modified from G. Balco, 2014) to estimate attenuation distances and model the production rate at each sample. Five rock-art sites have been dated and results range from 9.8±1.9 ka to 180.8±22.3 ka. While the date obtained for the youngest site can be interpreted as both a maximum and minimum age for the art due to its positioning over different walls of this specific shelter, all the other sites give maximum art ages which are significantly older than presumed human occupation in Australia. However, within the context of regional landscape geomorphology, these relatively young ages give new insights into the contrasting modes of landscape evolution in the Kimberley, and the importance of episodic escarpment retreat overprinted by passive basin-wide denudation which from numerous previous measurements are as low as 1-5 mm/ka (i.e. averaging timescales of ~400 kyr). A large number of similar sites in the region have been mapped and are potential candidates for this new approach which can constrain the controversial relative chronology of the various aboriginal rock art styles.

Realistic shell model and nuclei around ^{132}Sn

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In the last ten years or so, nuclei in the mass region around ^{132}Sn have become accessible to experimental studies thanks to new radioactive ion beam facilities and the development of sophisticated detection techniques. These nuclei represent a crucial opportunity to test the main ingredients of the nuclear-shell model and investigate the evolution of the shell structure when going far from stability valley in heavy-mass nuclei.

In the light- and medium-mass regions, structural changes have been evidenced for nuclei with a large excess of neutrons, leading to the breakdown of the traditional magic numbers and the appearance of new ones. These findings have driven a great theoretical effort to understand the microscopic mechanism underlying the shell evolution, with special attention to the role of the different components of the nuclear force (see, for instance, [1]).

The available experimental data for nuclei around ^{132}Sn, which are, however still scarce especially for systems with N>82, have shown peculiar properties although no clear signatures of modifications in the shell structure.

In this contribution, I shell focus on some selected results for nuclei with a few valence particles and/or holes with respect to ^{132}Sn, that have been obtained within the shell-model framework by using a microscopic effective interaction [2].

Calculations have been carried out by assuming a closed ^{132}Sn core and including the $0g_{9/2}1d2s0h_{11/2}$ and $0h_{9/2}1f2p0i_{13/2}$ orbitals for proton particles/neutron holes and neutron particles, respectively. A unique shell-model Hamiltonian is adopted, with the single-particle(hole) energies taken from experiment and the two-body effective interaction derived by means of the many-body perturbation theory [3] from the CD-Bonn nucleon-nucleon potential [4] renormalized by means of the $V_{\text{low-k}}$ approach [5].

Results are compared with experiments, and predictions that may provide guidance to future experiments are also discussed.

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Gamma-electron spectroscopy with Solenogam: Isomeric Decay in ^{145}Sm

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Solenogam is a recoil spectrometer designed for electron and gamma-ray spectroscopy at the ANU Heavy Ion Accelerator Facility. The design enables the study of nuclear excitations populated in the decay of long-lived states such as isomers and radioactive ground states. First used on a 6.5 T gas-filled solenoid for the study of isomeric decays in ^{189}Pb [1], Solenogam is now installed on an 8 T gas-filled solenoid and preliminary results for this configuration have been reported [2]. The solenoid is used to transport the products of fusion-evaporation reactions to a focal plane where Solenogam is situated, consisting of high-sensitivity gamma-ray and electron detector arrays for singles and coincidence measurements.

Among the N=83 isotones, high-spin isomers have been reported at $\sim$8 MeV for Z=60-68 [3]. Based on experimental g-factor measurements and quadrupole moments in ^{147}Gd [4], these states have been interpreted previously as shape isomers; however, in most cases the spin and parity assignments remain tentative. We have studied the decay of the high-spin, $t_{1/2}$=0.96 μs isomer in ^{145}Sm [5], using the ^{124}Sn(^{26}Mg,5n) reaction at a beam energy of 115 MeV. Microsecond chopped beams were used to isolate the isomeric decay resulting in a (longer) revised lifetime, while conversion coefficients were measured with Solenogam to confirm the isomer spin and parity for the first time. In addition, a significantly revised level scheme has been constructed. These results will be presented, together with an interpretation of the level structures supported by shell-model calculations performed using the K-Shell code [6].

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Status of the FAIR project

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The international FAIR project at GSI aims for an unprecedented facility for research with stable and radioactive ion and anti-proton beams. It will comprise of ion beam accelerators, storage rings, an anti-proton source, a fragment separator and experimental set-ups for four research pillars. These pillars are organized in large collaborations involving almost 3000 scientists: APPA for atomic and plasma physics, biology and material science, CBM for studies of compressed baryonic matter, NUSTAR for nuclear structure, reactions and astrophysics investigations, and PANDA for anti-proton studies. After a reorganisation in 2015, the FAIR project is progressing vigorously. Construction of the buildings and production of the machine and experiment components are on-going. Moreover, a scientific phase-0 program with the upgraded GSI accelerators and the already available FAIR sub-systems, e.g. the many NUSTAR set-ups has started.

NUSTAR relies primarily on the availability of exotic rare isotope beams produced by fragmentation reactions and fission of relativistic heavy ions. The fragment separator FRS and a versatile set of instruments, including gamma arrays, particle spectrometers and a storage ring enable unique experiments at GSI. The Super-FRS at the FAIR facility will provide several orders of magnitude stronger beams, enabling access to the extremes of nuclear stability. Continuous R&D efforts result in improved detectors and enable the NUSTAR collaboration to steadily enhance the sensitivity and selectivity limit of their experiments. Beyond providing new insights into the nature of atomic nuclei and their creation in the universe, important technological applications for the benefit of our society arise from NUSTAR developments.

The status of FAIR and NUSTAR will be reported, the opportunities for NUSTAR experiments in FAIR phase-0 at GSI and at Day-1 at FAIR will be discussed, and novel applications will be introduced.

Ion Laser Interaction AMS: Why poor gas gives pure beams

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Isobars, i.e. atomic or molecular ions of almost the same mass as the ion of interest, are *the* challenge in (Accelerator) Mass Spectrometry. Exploiting electronic properties of the isobaric anions at sub-eV kinetic energies is becoming a breakthrough for isobar suppression. Key of a new method implemented at the Vienna Environmental Research Accelerator (VERA) is the photo-detachment of the unwanted isobars in a linear, gas-filled radio-frequency quadrupole (gf-RFQ) by a suitable laser. Isobar suppression by more than ten orders of magnitude has been reached, e.g. for Cl-36 over S-36. The fundamental prerequisite is: the negative ions of interest must remain unaffected by the interaction. For laser light this is the case if their electron affinity is greater than the photon energy. The use of pure Helium as the stopping medium - another prerequisite for slow anions to pass the gf-RFQ unaffected - turned out not to be fundamentally important. In fact, we see in several cases that ion-molecule reactions with small "impurities" (a few percent) of Hydrogen or Oxygen in Helium gas can reduce unwanted isobaric molecules by orders of magnitude with little effect on the molecules of interest. This "reaction cell chemistry" is highly welcome, but needs to be better understood. So far, we get sufficient and reliable isobar suppression only in combination with laser-photodetachment.

Enhanced collectivity of neutron-rich ^{129}Sb beyond the particle-core coupling scheme

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The region around the double-magic ^{132}Sn has been of interest in recent years, with Radioactive Ion Beam accelerator facilities allowing experiments to be conducted in neutron-rich nuclei. Experimental evidence shows ^{132}Sn to be one of the best doubly magic nuclei, providing a testing ground for the shell model and investigations into the onset of collectivity.

Coulomb excitation data from the Holifield Radioactive Beam Facility (HRIBF) at Oak Ridge National Laboratory will be presented. 11 HPGe Clover detectors in the Clarion array and 54 CsI particle detectors in the BareBall array were used to study ^{129}Sb, a radioactive nucleus near ^{132}Sn. The measurements provide a test of particle-core coupling schemes.

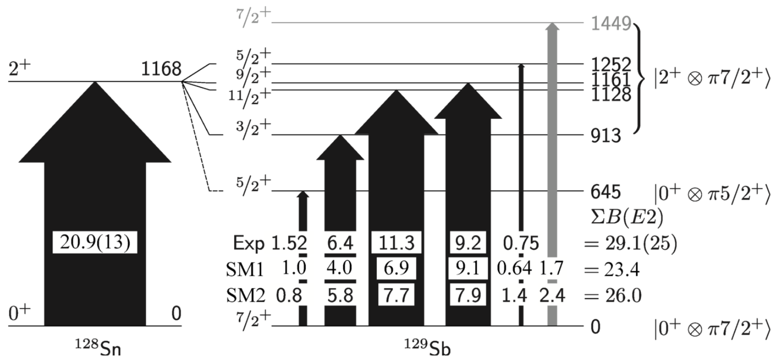

FIG. 1: Fragmentation of the $B(E2)$ strength in the ^{128}Sn core into the $d_{5/2}$ proton and $2^+ \otimes g_{7/2}$ multiplet members is shown.

The results indicate that the total electric quadruple strength exciting the $2^+ \otimes g_{7/2}$ multiplet of ^{129}Sb is a factor of 1.39(11) larger than that of the 2^+ excitation of the ^{128}Sn core. This is in stark contrast to the expectations of particle-core coupling schemes [1, 2]. The odd proton must polarize the core. Two state-of-the-art shell-model calculations were performed, which account for some but not all of the enhanced collectivity.

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Fragmentation analysis of ^{88}Mo* compound nucleus in view of different decay mechanisms

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In reference to the experimental data [1], the decay mechanism of ^{88}Mo* compound system formed in ^{48}Ti+^{40}Ca reaction is investigated at three beam energies (E_{beam}=300, 450, and 600 MeV) using the collective clusterization approach of Dynamical Cluster decay Model (DCM) [2, 3]. The calculations are done for spherical choice of fragmentation and with the inclusion of quadrupole (β_2) deformations having optimum orientations (θ_i^{opt}). According to the experimental evidence [1] ^{88}Mo* decays via fusion-evaporation (FE) and fusion-fission (FF) processes, thus the decay cross-sections of this hot and rotating compound system are calculated for both FE and FF channels. In FF decay mode, the explicit contribution of intermediate mass fragments (IMF), heavy mass fragments (HMF) and symmetric fission fragments is extracted within DCM framework. The calculated FE and FF decay cross-sections find nice agreement with the available experimental data [1] for both the choices of fragmentation (spherical as well as β_2-deformed). Experimentally, it has been observed that the total contribution of FE and FF decay cross-sections is much less than the total reaction cross-sections (estimated according to [4]), suggesting the presence of some nCN component such as deep inelastic collisions (DIC), which generally contributes at higher ℓ-values or above critical angular momentum (ℓ_{cr}). In view of this, DIC contribution is also investigated.

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The status of the new AMS device for medium mass isotopes at the Cologne University

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A new device has been set up at the Cologne 10 MV FN accelerator to perform medium mass AMS measurements, e. g. ^{53}Mn and ^{60}Fe. It consists of an achromatic injector with an MC-SNICS ion source (electrostatic analyzer and magnet radius of 0.435 m) with a fast injection system for the switching between the stable and rare ion beam. With the accelerator ion energies of 100 MeV are accessible by the use of the 10^+ charge state and reliable terminal voltages of 9.5 MV. The achromatic high energy mass spectrometer consists of a 90° analyzing magnet (r=1.1 m) followed by a multi Faraday offset cup chamber and a 30° electrostatic analyzer (r=3.5 m). The isobar separation will be done with an isotope specific multi step energy loss measurement with combinations of silicon-nitride foils, the ESA, a 4 m time-of-flight system and a gas ionization detector. Additionally a 135° magnet (r=0.9 m) can be used in gas-filled mode for measurements like ^{60}Fe.
The current project intends to use the production of ^{53}Mn and ^{3}He in iron-tianium-oxides for the isochron burial dating technique with an upper dating range of 25 Ma for long term erosion processes. So far we are able to measure (^{53}Mn/^{55}Mn) isotopic ratios with a blank value of $1.55\text{x}10^{-12}$.

After the first successful ^{53}Mn and ^{60}Fe test measurements it revealed that some improvements of the new set-up should be made: (i) A larger entrance window at the ionization detector will increase the overall transmission. (ii) The Installation of time of flight detectors for the gas-filled magnet will increase the suppression. (iii) Modification of the cathode electrodes are planned to reach a better angular resolution, which will enable to discriminate scattered beam particles. By these improvements we expect to optimize the system so that we can meet the design values for the geological applications with a blank level of $1.0\text{x}10^{-13}$.

In addition further improvements on the FN-AMS-setup will be performed: e.g. increasing the efficiency of the injector, especially of the ion source.

Achieving the ultimate sensitivity in Accelerator Mass Spectrometry of high mass isotopes

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The VEGA AMS system at ANSTO, based on a 1MV tandem accelerator, was custom-designed to achieve the highest possible sensitivity for high mass isotopes [1]. It incorporates multiple medium-resolving power analysing elements: one magnetic element for the injected negative ions, followed by magnetic, electrostatic and second magnetic elements for positive ions after acceleration. This design, with mass and energy resolving powers in the range 500 to 1000, separates isotopes and suppresses backgrounds that may originate from a variety of ion species. The gas stripper in the high-voltage terminal is key both to system efficiency and to background suppression. Helium gas stripping is used, providing around 40% ion yield to the most abundant charge state (3+). The stripper pressure must be sufficient to break up all molecules while minimising the scattering angle of the ions as they undergo charge-changing collisions. Our recent work [1] has demonstrated that the need for production of negative molecular ions in AMS of actinides is not such a barrier to high efficiency: the VEGA sputter ion source can achieve greater than 1% efficiency for production of plutonium oxide negative ions and so overall sensitivity to a few hundred atoms in a sample is possible.

We are involved in a number of projects requiring high sensitivity and low backgrounds. Examples include (1) the detection of ^{244}Pu of extraterrestrial origin in deep oceanic ferromanganese crusts [2,3]; (2) radioecology of plutonium in the environment of former nuclear test sites [4,5]; (3) detection of nuclear signatures for nuclear safeguards and forensics; use of Pu in global fallout as a chrono-marker in environmental studies [6]; (4) measurement of platinum-group-element isotope ratios in meteorites; (5) evaluation of the radio-purity of materials for use in dark matter searches.

Each of these projects presents their own particular challenges. In some cases, sensitivity is limited by background from scattered ions of species other than the one of interest. In other situations, cross-contamination between samples, in the sample prep lab or ion source, limits sensitivity. Other projects or previous uses of laboratories may leave residual contamination. For stable and very long-lived species, such as PGEs and major uranium isotopes, the ubiquity of those species at low levels in almost all materials sets limits.

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Shape coexistence in mass 40 region studied via E0 and gamma transitions

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The advent of shape coexistence is a unique feature of atomic nucleus. This phenomenon particularly occurs near spherical closed shell nucleus, where the onset of shape coexistence is based on the balance between stabilizing effect of closed shells to retain spherical shape and the residual interaction which drives the nucleus to deformed shape [1].

The spherical doubly magic nucleus, ^{40}Ca, is a best example exhibiting such shape coexistence. A unique feature of ^{40}Ca is an appearance of low-lying 0^+ states. First excited state is 0^+ at 3.3 MeV and the second excited 0^+ state closely locates at 5.2 MeV. These states are understood as band heads of the normal deformed and the superdeformed bands, respectively [2], which corresponds to the multiple shape coexistence in ^{40}Ca. Similarly, low-lying 0^+ SD band heads are also observed in neighboring nuclei of mass 40 region [3,4,5].

Existence of the superdeformed (SD) band starting from the 0^+ band head is another unique feature of ^{40}Ca. Although the existence of superdeformed nuclei are reported in many nuclei of various mass regions, A=60, 80, 130, 150, 190 [3], the superdeformed band head 0^+ states are only observed in mass 40 region [4,5], and in the fission isomer region [3]. Such situation makes it difficult to understand the property of superdeformed state, such as the mixing of the states with different configurations. Therefore, ^{40}Ca is a quite unique nucleus where one can study the electric monopole (E0) transition strength between the band head of superdeformed state and the spherical ground state, which directly reflects the shape mixing [6].

In order to study the property of superdeformed state of ^{40}Ca, we have performed an experiment to measure the E0 transition from the excited 0^+ states. Experiment was carried out using a ^{40}Ca(p,p') reaction at the 14UD tandem accelerator facility in Australian National University. The Super-e pair spectrometer [7,8,9], a superconducting magnetic-lens spectrometer, is employed to measure conversion electrons and electron-positron pairs with excellent background suppression. A single germanium detector was also used to measure gamma transitions from the excited states simultaneously.

In the presentation, the experimental results on E0 transition strength from the normal deformed and superdeformed band in ^{40}Ca and the theoretical studies based on the large-scale shell model calculation will be discussed. Recent results studied via gamma transitions in mass 40 region will be also presented and discussed.

This work is partially supported by the International Joint Research Promotion Program of Osaka University and JSPS KAKENHI Grant Number JP 17H02893.

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Evidence for Recent Interstellar ^{60}Fe on Earth

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Over the last 20 years the long-lived radionuclide ^{60}Fe with a half-life of 2.6 Myr was shown to be an expedient astrophysical tracer to detect freshly synthesized stardust on Earth.
The unprecedented sensitivity of Accelerator Mass Spectrometry for ^{60}Fe at The Australian National University (ANU) and Technical University of Munich (TUM) allowed us to detect minute amounts of ^{60}Fe in deep-sea crusts, nodules, sediments and on the Moon [1-5]. These signals, around 2-3 Myr and 6.5-9 Myr before present, were interpreted as a signature from nearby Supernovae which synthesized and ejected ^{60}Fe into the local interstellar medium.

Triggered by these findings, ANU and TUM independently analyzed recent surface material for ^{60}Fe, deep-sea sediments and for the first time Antarctic snow, respectively [6, 7].
We find in both terrestrial archives corresponding amounts of recent ^{60}Fe.
We will present these discoveries, evaluate the origin of this recent influx and bring it into line with previously reported ancient ^{60}Fe findings.

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Masses and Beta-Decay Spectroscopy of Neutron-Rich Nuclei: Isomers and Sub-shell Gaps with Large Deformation *

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The structure of deformed, neutron-rich nuclei in the rare-earth region is of significant interest for both the nuclear-structure and astrophysics fields. Although much progress is being made in our understanding of the r-process, a satisfactory explanation for the elemental peak in abundance near A=160 is still elusive. Understanding the origin of this peak may be a key to correctly identifying the astrophysical conditions for the r-process. Theoretical models of element production are dependent on masses and lifetimes of neutron-rich, deformed rare-earth nuclei in this region where little or no information is known. The available nuclear structure information is also scarce, owing to difficulties in the production of these nuclei. In order to address these issues, an experimental program has been initiated at Argonne National Laboratory using high-purity radioactive beams produced by the CARIBU facility. Mass measurements using the Canadian Penning Trap (CPT) and beta-gamma coincidence studies using the SATURN moving tape system and the X-Array spectrometer, comprising of five Ge clover detectors, were carried out. A number of two-quasiparicle isomers were discovered in odd-odd nuclei using CPT and in several cases their properties were elucidated by complementary beta-decay studies. Evidences were found for changes in the single-particle structure, which in turn resulted in the formation of a sizable sub-shell gap at N=98 and large deformation. Results from these measurements will be presented, together with predictions based on deformed shell model that includes effects of pairing and spin-depended, nucleon-nucleon interactions. The newly-commissioned beta-decay station at Gammasphere will also be discussed and results from the first experimental campaign will also be presented.

* This work is funded by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357 (ANL) and the National Science Foundation under Grant No. PHY-1203100 (USNA). This research used resources of Argonne National Laboratory's ATLAS facility, which is a DOE Office of Science User Facility.

Confirmation the existence of the X17 particle

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Recently, we used the ^{7}Li(p,e^{+}e^{-})^{8}Be reaction to excite an 18.15 MeV excited state in ^{8}Be and observed its internal pair (e^{+}e^{-}) decay to the ground state. An anomaly in the form of peak-like enhancement relative to the internal pair creation was observed at large angles in the angular correlation [1]. It turned out that this could be a first hint for a 17 MeV X-boson (X17), which may connect our visible world with Dark Matter [2]. The possible relation of the X17 to the Dark Matter problem triggered great theoretical and experimental interest in the particle, hadron, nuclear and atomic physics communities. Zhang and Miller discussed in detail whether a possible explanation of nuclear physics origin could be found [3]. They have not found any of such explanation.

Using a significantly modified and improved experimental setup, we reinvestigated the anomaly observed in the e^{+}e^{-} angular correlation by using a new tandetron accelerator of our institute. This setup has different efficiency curve as a function of the correlation angle, and different sensitivity to cosmic rays yielding practically independent experimental results. In this experiment, the previous data were reproduced within the error bars.

To confirm the existence of the X17 boson, we conducted a search for similar anomaly in another nuclear transition. The 0→ $^{-}$ 0^{+} transition in ^{4}He, which energy is 21.1 MeV, was chosen. If X17 is a vector boson with $J^{\pi}=1^{+}$ [2] then the emission can be done with L=1 angular momentum, while in case of the X17 is an axion like particle (ALP) [4] then it can be emitted with L=0. The 21.1 MeV ($J^{\pi}=0^{-}$) state is broad, Γ=0.84 MeV, and it overlaps with the first excited state located at E_x=20.21 MeV ($J^{\pi}=0^{+}$, Γ=0.50 MeV), but it did not complicate our results.

We used proton resonant capture reaction on ^{3}H target at a beam energy of E_p= 0.90 MeV, and this way, we excited both of the above overlapping states. We observed e^{+}e^{-} pairs with an angular correlation characteristic basically to the external pair creation (EPC) of the γ-rays created in the direct capture process of the ^{3}H(p,γ)^{4}He reaction and no contribution from the week 0^{+} → 0^{+} E0 process. On top of the EPC background a peak at $\Theta\approx115°$ is clearly visible with larger than 5σ confidence. According to our simulations performed with GEANT4, this peak corresponds to the decay of the X17 boson created in the 0→ $^{-}$ 0^{+} transition.

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The movements of Alpine glaciers throughout the last 10,000 years as sensitive proxies of temperature and climate changes

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It is well known that the Holocene, i.e. the geological time period of the last 10,000 years following the end of the Ice Age, enjoyed relatively stable temperatures. But glaciers are sensitive proxies to even small temperature and/or climate changes. Thus, the globally observed retreat of Alpine glaciers and polar ices sheets since 1850 AD (the end of the so-called Little Ice Age) has been linked to the temperature increase caused by human activities, particularly due to the steady increase of CO_2 in the atmosphere [1]. On the other hand, it is now evident that considerable glacial fluctuations occurred already at much earlier times when human impact was negligible.

In a way, the interest in Alpine glaciers of the past started with the accidental discovery of the famous Iceman Ötzi in 1991, a naturally mummified body which was well preserved for 5200 years in the icy environment of a high mountain pass (3210 m a.s.l.) in the Ötztal Alps [2]. Since then, several forward and backward movements of glaciers in the European Alps and in the New Zealand Southern Alps throughout the last 10,000 years have been established with the help of dendrochronology, radiocarbon dating, surface exposure dating of rocks and moraines with various cosmogenic radionuclides (^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl), and geomorphological considerations [3].

It is possible that small solar activity variations, enhanced by (hitherto largely unknown) feed-back processes on Earth, caused the observed glacial fluctuations. These natural fluctuations constitute a "background", which is now being modified in a complex way by human activities. It is hoped that research on the movement of Alpine glaciers before man's influence may actually help to better assess the anthropogenic influence on climate change in our time.

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SABRE and the Stawell Underground Physics Laboratory: Dark Matter Research at the Australian National University

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The direct detection of dark matter is a key problem in astroparticle physics that generally requires the use of deep-underground laboratories for a low-background environment where the rare signals from dark matter interactions can be observed. The dark matter interaction rate from Weakly Interacting Massive Particles (WIMPs) in an Earth-based detector, is expected to modulate yearly due to the change of the Earth's speed relative to the galactic halo reference frame. There is a long-standing result from the DAMA experiment at the Gran Sasso National Laboratory (LNGS) in Italy that used NaI(Tl) scintillator for the detector medium; their observed results are consistent with this scenario [1,2,3]. However, the magnitude of the signal is in tension with a number of other direct detection measurements that use different detector technologies [4].

SABRE (Sodium-iodide with Active Background REjection) is a new NaI(Tl) experiment [5,6] designed to search for galactic dark matter through the annual modulation signature. Arrays of NaI(Tl) detectors with unprecedented radio-purity will be operated inside volumes of active liquid scintillator to veto against both external and internal backgrounds, especially the 3 keV signature from the decay of trace amounts of ^{40}K within the crystals. SABRE will be a dual-site experiment located at both LNGS (Italy) and at the Stawell Underground Physics Laboratory under development in Victoria, Australia, that involves over 50 people from more than a dozen institutions in Europe, Australia and the US. The operation of twin full scale experiments in both the northern and southern hemispheres is an important factor that will strengthen the reliability of a dark matter detection result by discriminating against possible seasonal systematic effects.

SABRE relies on detector materials and measurement techniques from nuclear physics. This presentation will describe the SABRE experiment, plans for the new laboratory in Australia (anticipated to be the first deep underground laboratory operational in the southern hemisphere), and the results from nuclear physics experiments performed at the Australian National University with our 14UD tandem accelerator that support the SABRE detector development effort.

The SABRE experiment has been the instigator for a cohesive program of Australian effort in dark matter research (WIMPs, WISPs, indirect detection, theory) and the status of this program and future effort will also be briefly described.

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Beyond ^{132}Sn

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Exotic nuclei beyond the ^{132}Sn double shell-closure are influenced by both the Sn superfluity and the evolving collectivity only a few nucleons away. Toward even more neutron-rich nuclei, for example at intermediate mass number A~136, the interplay between single-particle and collective particle-hole excitations is evident. In some cases with the extreme addition of neutrons also other effects may be expected such as the formation of neutron skin, stabilization as sub-shell gap or orbital crossings [1,2].

The knowledge of nuclear ingredients is especially interesting beyond ^{132}Sn as little is known on how the excitation modes develop with the addition of both protons and neutrons. Therefore, systematic prompt and decay studies can be such sensitive probe for their structure [3,4]. Aiming to provide a more global picture and understand this barely explored neutron-rich portion of the nuclear chart, we have performed several investigations.

We have produced the nuclei of interest following fission as ^{238}U on ^{9}Be, thermal n-induced fission on ^{241}Pu and ^{235}U or fast n-induced fission on ^{238}U and ^{232}Th in recent γ-ray spectroscopy projects [2-5]. Consistent data analysis allows to access various spins and excitation energies and to provide new input to theory. Examples from these studies on isotopes with A~140 will be presented along with the possible interpretation of the new data.

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Ion-Laser InterAction Mass Spectrometry and the quest for AMS of ^{182}Hf

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The long-lived trace isotope ^{182}Hf ($T_{1/2}$ = 8.9 Ma) is of high astrophysical interest as its potential abundance in environmental archives would provide rare insight into heavy element nucleosynthesis in recent r-process events in the vicinity of our planet. Despite substantial efforts, however, it could not be measured at its natural abundance level with conventional AMS so far due to strong isobaric interference from stable ^{182}W. The new Ion Laser InterAction Mass Spectrometry (ILIAMS) technique at the Vienna Environmental Research Accelerator (VERA) tackles the problem of elemental selectivity in AMS with a novel approach. It achieves near-complete suppression of isobar contaminants via selective laser photodetachment of decelerated anion beams in a gas-filled radio frequency quadrupole (RFQ) [1,2]. The technique exploits differences in electron affinities (EA) within elemental or molecular isobaric systems neutralizing anions with EAs smaller than the photon energy. In addition, collisional detachment or chemical reactions with the buffer gas can further enhance anion separation.

In this contribution, we will highlight the potential of this new technique based on recently conducted AMS-measurements of ^{90}Sr ($T_{1/2}$ = 28.64 a), where ILIAMS achieves an isobar suppression factor $>10^7$. The application of ILIAMS improves the detection limit by a factor 40 compared to the previous AMS-benchmark. We will then present first results with this approach on the even more challenging detection of ^{182}Hf. With He+O_2 mixtures as buffer gas in the RFQ, suppression of $^{182}WF_5^-$ vs $^{180}HfF_5^-$ by $>10^5$ has been demonstrated. Mass analysis of the ejected anion beam identified the formation of oxyfluorides as an important reaction channel. The overall Hf-detection efficiency at VERA presently is 1.4×10^{-3} and the W-corrected blank value ^{182}Hf/^{180}Hf = $(3.4 \pm 2.1) \times 10^{-14}$. In addition, a survey of several sputter materials for highest negative ion yields of HfF_5^- has been conducted. Finally we will give an outlook on ways to proceed in order to detect ^{182}Hf at astrophysical levels.

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Production of exotic radionuclides targets for nuclear astrophysics experiments

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This contribution aims to present the last developments, in term of design and manufacturing, of exotic radionuclides targetry, for nuclear astrophysics experiments. Particular emphasis is given to the description of the used preparation methods, i.e. electrodeposition/molecular plating, casting and ion implantation. Target characterization, in terms of deposited activities and spatial distributions, is addressed as well. In this context, two methods developed at the , Paul Scherrer Institut, based on alpha spectrometry coupled with the advanced alpha-spectroscopy simulation program, and gamma spectroscopy coupled with a screaming device and radiographic imaging, respectively, are presented.

Modelling Hyperfine Interactions to Perform Picosecond-lifetime Nuclear g-factor Measurements

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The nuclear g factor is a useful metric for probing nuclear structure. This is because the g factor is sensitive to the angular momentum of unpaired nucleons. Particularly, in some regions of the nuclear chart $g(2_1^+)$ values in even-even nuclei can be used to probe sub-shell closures [1]. Therefore, comparisons between theoretical and experimental g factors are valuable. However, such states often have lifetimes in the picosecond range, making for challenging measurements. One technique for performing such measurements utilises the hyperfine field of recoiling ions in vacuum (RIV) [2]. While this technique has been successful in some cases, there are others in which complex atomic interactions complicate the measurement [3].

In order to utilise the RIV technique for such complex interactions the hyperfine interaction must be modelled. However, to model the interaction, detailed atomic-structure information must be known. Chen *et al.* developed a Monte-Carlo approach [4], with atomic structure information calculated using the General Relativistic Atomic Structure Package (GRASP) [5]. Considering nuclei recoiling out of a foil into vacuum, we know there exists a distribution of charge states and energies. The method is to allow for a number of atomic states, for each charge state, to be randomly populated. By treating decays in each state separately, their average interaction can be determined at a given time. This approach was found to agree with RIV data from ^{122,130,132}Te measurements and their reported $g(2_1^+)$ values [4].

In this work, a new approach similar to that of Chen *et al.* [4] will be presented. The new approach utilises a more realistic coupled-tensor evolution and allows for different types of atomic-state distribution. Additionally, atomic structure calculations have been performed using a more recent release of the GRASP [6], which utilises improved algorithms for wavefunction convergence. The effect of using the coupled-tensor approach, and also of the different atomic-state distributions, will be examined. Fits to experimental data will be presented, and the feasibility of determining g factors will be reviewed. Finally, the GRASP calculations will be scrutinised, in part to build confidence in their use, but also to identify uncertainties.

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Sample preparation for AMS astrophysics projects – Size does (not) matter

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The determination of long-lived radionuclides by means of accelerator mass spectrometry (AMS) is usually outstandingly successful when an interdisciplinary team comes together. The "heart" of AMS research is of course an accelerator equipped with sophisticated ion sources, analytical tools and detectors run by experienced and ambitious physicists [e.g. 1-3]. Setting-up and further developing AMS systems is one of the most interesting and challenging topics. The reputation to be reached here is the greatest uniqueness of analysis possible, lowest detection levels, and/or most reliable data world-wide.

For sure, another primary pillar of AMS research is based on the questions addressed within fundamental and applied research. "How have supernovae explosions influenced Earth, our solar system and beyond?" [e.g. 4] or "How does the Earth's surface and environment respond to earthquakes, climate change and anthropogenic influences?" [e.g. 5] are just two examples of high-quality studies.

However, somehow in-between there are groups of hidden figures like people developing software for data analysis or performing the required chemical sample preparation for AMS. These often unacknowledged individuals do crucial work for the overall outcome of the studies.

Chemists can spend weeks and months trying (and failing) on sample preparation before they find a "safe way" and start the actual work on the most valuable sample material, repeat all over again the same "recipe" for hundreds of samples, or train non-chemists the secrets of their successful recipes. Nevertheless, interdisciplinary AMS work can also be very exciting for a chemist: touching (and destroying) samples from outer space, the deep ocean or (currently) frozen places like Antarctica is quite thrilling. But at the end of the day, the whole AMS chemist's work can be described as "reducing the sample matrix, other impurities and especially isobars to a level the AMS machine can handle while enriching the radionuclide of interest".

Starting materials for applications such as astrophysical research can be "orders of magnitude" different: a neutron-irradiated sample of 1 g tungsten powder [6], over 40 g of clay-rich material from the Cretaceous–Tertiary (K-T) boundary, 100 g of ultra-pure sodium iodide, or 500 kg of snow from Antarctica [4] can cause totally different and sometimes unexpected problems in the chemistry lab. In general, smaller samples are not always easier to handle for example if they are chemically rather resistant or reactive. The cream of the crop of failure and success in a few AMS chemistry labs will be presented.

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Shape coexistence in the neutron-deficient nuclei near Z=82

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Since the first application of isotope-shift measurements a sharp shape transition in the ground states of light odd-mass mercury isotopes was observed, and shape coexistence near the Z=82 shell has been an actively studied phenomenon. In neutron-deficient even-mass mercury isotopes a weakly deformed oblate ground-state band is found to coexist with a more deformed prolate band. The prolate states are interpreted as a π(4p-6h) excitation across the Z=82 shell gap. The prolate band build upon an excited 0^+ state can be related to similar structures in the Pb nuclei. The energy of this prolate structure is lowest in ^{182}Hg and shows a parabolic trend of excitation energy as a function of the neutron number. In the neighboring even-mass platinum isotopes this structure reaches even the ground state. In the Hg isotopes ^{180}Hg is the most exotic nucleus for which lifetimes of excited states are known so far. These can be used to determine model-independent B(E2)-values and absolute values of deformation employing the rotor model. A breakdown of the shape-coexistence is predicted with further decreasing neutron number. We will present lifetime measurements of excited states in ^{178}Hg using the Recoil Distance Doppler-Shift (RDDS) method. The recoil-decay tagging (RDT) technique was applied to select the ^{178}Hg nuclei and associate the prompt γ-rays with the correlated characteristic ground state α-decay.

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Sub-Saharan Climatic Catastrophe Forewarned by AMS

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With one notable exception, World leaders have accepted the irrefutable evidence that climate change is happening and represents one of the most important issues - if not the most important issue - that affects all corners of our planet and our collective future along with it. The denialist point-of-view continues to be trumpeted from some quarters and as such has to be refuted through fact gained via scientific measurements that show that this is not only happening in the here and now, but will worsen into the future unless appropriate measures are taken with all due haste.

The evidence presented here is derived from an ongoing study of baobab trees in sub-Saharan Africa in which growth patterns are shown to be correlated with temperature and dryness. Along with results that stretch as far back as the beginning of the twentieth century, these correlations are well-reproduced by climate models and therefore their predictions that sub-Saharan Africa will become hotter and dryer have to be taken seriously along with all consequences thereof.

By their nature, baobabs do not grow within a forest, a wood or even a copse but stand apart from each other as sentinels of the savannah so that there is no closed arboreal canopy. As such they are excellent indicators of the dryness of the environment in which they grow and since dryness is intimately correlated with temperature, they give a record of the temperature at that location. This was derived from the measurement of the ratio of the two stable isotopes of Carbon, namely Carbon-12 and Carbon-13 as shown in figure 1. However, baobabs tend to be multi-stemmed, that is they do not have a single trunk with a single set of growth rings. Moreover, when it is too dry, baobabs will not lay down an annual growth ring in one or any of the multi-stems of the fused trunk. In fact, they may not lay down a growth ring for decades or may grow up to five or six rings in a single year. Thus, this necessitates the explicit dating of each ring via radio-carbon measurements as undertaken with Accelerator Mass Spectrometry (AMS) in order to date the Carbon-12/Carbon-13 ratios and hence the climate characteristics derived from them. The AMS facility at the TAMS department of iThemba LABS has undertaken a considerable number of Carbon-14 measurements for this project and the latest results will be presented.

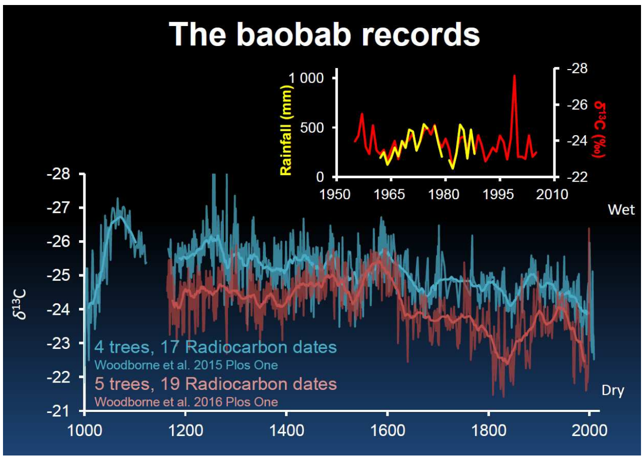

Figure 1 : $\delta^{13}C$ values for baobab trees dated with C-14 AMS measurements. The $\delta^{13}C$ values extracted from tree rings illustrate how wet or dry the environment in which the tree was growing at that time shown on the x-axis (calculated calendar year) as derived from the C-14 AMS results.

A study of the excited 0^+ states in ^{188}Pb

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In Pb isotopes close to the neutron mid-shell at N=104, experimental evidence for shape-coexisting configurations and associated collective bands has been observed. These structures intrude down to energies close to the spherical ground state and can be associated with intruder 2*p*-2*h* and 4*p*-4*h* proton shell-model excitations across the Z=82 energy gap. Calculations using the deformed mean-field approach, essentially equivalent to the shell-model method, reveal three different shapes (spherical, oblate and prolate configurations). It remains a challenge for both theoretical and experimental studies to obtain a consistent and detailed description of all the observed phenomena.

The low-lying excited 0^+ states in ^{188}Pb have been probed in γ-decay fine structure studies or in-beam conversion electron measurements. γ-ray experiments have identified an exited 0_2^+ state at 591 keV and associated it with a prolate structure [1,2]. These findings are in contrast with earlier measurements which reported a 0_2^+ at ~570 keV [3,4]. Candidates for the 0_3^+ state associated with a prolate at 767 keV was also proposed by Allatt et al. [4]. An in-beam conversion electron spectroscopy measurement performed by Le Coz et al., proposed the two low-lying 0^+ states at 591 keV (oblate) and 725 keV (prolate) [5]. Consequently, together with the spherical ground state, the three 0^+ states with largely different structures reflect the triple-shape coexistence phenomenon in ^{188}Pb. Moreover, the triple-shape coexistence has been revealed by the existence of three isomeric states associated with different structures (spherical 12^+, oblate 11^- and prolate 8^-) and characteristic band structures on top of these states [6].

In this presentation we will discuss the simultaneous in-beam measurement of γ rays and internal conversion electrons of ^{188}Pb performed at the Accelerator Laboratory of the University of Jyväskylä, Finland, employing the SAGE spectrometer [7]. We will introduce our findings on the excited 0^+ states and the interband transitions and present our state-of-the-art simulation code employing the NPTOOL framework [8] in Geant4 [9].

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The MARA Low-Energy Branch – towards day 1

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The MARA low-energy branch (MARA-LEB) [1,2] is a novel facility currently under development at the University of Jyväskylä. Its main focus will be the study of ground-state properties of exotic proton-rich nuclei employing in-gas-cell and in-gas-jet resonance ionisation spectroscopy and mass measurements of nuclei close to the N=Z line of particular interest to the astrophysical rp process [3].

MARA-LEB will combine the MARA vacuum-mode mass separator [4] with a gas cell, an ion guide system and a dipole mass separator for stopping, thermalising and transporting reaction products to the experimental stations. The gas cell has been designed and built based on a concept developed at KU Leuven [5].

Following extraction from the cell the ions will be transferred by radiofrequency ion guides and accelerated towards a magnetic dipole for further mass separation before transportation to the experimental setups [6]. Laser ionisation will be possible either in the gas cell or in the gas jet using a dedicated Ti:Sapphire laser system and will provide reliable experimental data on the ground-state properties of exotic isotopes close to the N=Z line.

Mass measurements will be achieved through a dedicated radiofrequency quadrupole cooler and buncher and a multiple-reflection time-of-flight mass spectrometer [7] which will be combined with the facility. These devices will allow for mass measurements of several isotopes with high impact on the rp process and which could be used as test grounds for state-of-the-art nuclear models.

In this presentation we will give an update on the current state of the MARA-LEB facility and discuss the development of individual parts.

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Study of Astrophysical *s*-Process Neutron Capture Reactions at the High-Intensity SARAF-LiLiT Neutron Source

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We report on recent experiments at the Soreq Applied Research Accelerator Facility - Liquid-Lithium Target (SARAF-LiLiT) laboratory dedicated to the study of s-process neutron capture reactions. The mA-proton beam at 1.92 MeV (2–3 kW) from SARAF Phase I yields high-intensity 30 keV quasi-Maxwellian neutrons ($3–5\times10^{10}$ n/s). The high neutron intensity enables Maxwellian averaged cross sections (MACS) measurements of low-abundance or radioactive targets. Neutron capture reactions on the important *s*-process branching points ^{147}Pm and ^{171}Tm were investigated by activation in the LiLiT neutron beam and γ-measurements of their decay products. MACS values at 30 keV extracted from the experimental spectrum-averaged cross sections are obtained and will be discussed. The Kr region, at the border between the so-called weak and strong s-process was also investigated. Atom Trap Trace Analysis (ATTA) was used for the first time for the measurement of a nuclear reaction cross section and the MACS(30 keV) of the ^{80}Kr$(n,\gamma)^{81}$Kr($t_{1/2}$= 230 ky) and ^{84}Kr$(n,\gamma)^{85g}$Kr(10.8 y) were determined. The latter determination was confirmed both by low-level β counting and γ spectrometry while the shorter capture products ^{79,85m,87}Kr were detected by γ-spectrometry only. The partial MACS leading to ^{85m}Kr(4.5 h) measured in this experiment has interesting implications since this state decays preferentially by β decay (79%) to ^{85}Rb on a faster time scale than does ^{85g}Kr and behaves thus as an *s*-process branching point. This work was supported in part by Pazy Foundation (Israel) and Israel Science Foundation.

Single atom counting of ^{55}Fe for explosive stellar nucleosynthesis studies

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Explosive stellar burning is a major contributor to the nucleosynthesis of elements in the mass region around iron. Relevant reactions for these stellar scenarios (e.g. α- or p-capture), involve charged particles at energies in the low MeV range. Proper tuning of theoretical nuclear models and astrophysical network calculations, aiming to reproduce elemental and isotopic abundance rely on the availability of experimental cross section data. In particular cross sections of charged particle-induced reactions near the reaction threshold are very sensitive to model parameters but experimental data is often limited. For example, no suitable experimental data are published for the ^{52}Cr(α,n)^{55}Fe reaction. Although ^{55}Fe is rather short-lived [$t_{1/2}$=(2.744±0.009) a][1] the small cross sections at the relevant particle energies and weak γ-transitions in the ^{55}Fe decay, make decay counting very challenging.

A combination of α-particle irradiation and Accelerator Mass Spectrometry (AMS) measurements was used to determine the cross section for the reaction ^{52}Cr(α,n)^{55}Fe for astrophysically important energies. Thin layers of Cr, evaporated on Al foils, were irradiated with α-particles of 4.5-10 MeV from the cyclotron accelerator at Atomki. Following irradiation, the Cr-Al foils were dissolved, spiked with natural Fe carrier and converted into Fe_2O_3. The ^{55}Fe/^{56}Fe ratio of the samples was determined by AMS and cross sections as low as 3 μb are reported.

Our results for energies above 6 MeV are in excellent agreement with theoretical predictions. At lower energies the experimental data suggest smaller cross sections than theory, by up to a factor of three. The new experimental data provide anchor points for alpha capture reactions in the Fe mass region near their reaction thresholds and also helps to study the alpha nucleus optical potential.

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Effect of N/Z and dissipation in the fission of ^{212,214,216}Ra nuclei via neutron multiplicity measurements

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Pre-scission neutron multiplicity (ν_{pre}) is one of the best probes to understand the evolution of the compound nucleus formed in heavy ion fusion. Measured ν_{pre} is observed to be larger than the standard statistical model (SSM) [1] predictions in many cases [2, 3] and were attributed to the dynamical delay or dissipation involved in fission. A few attempts have been made to understand the effect of neutron shell closure, N/Z and dissipation in fission dynamics. The deduced dissipation strength is shown to have a strong temperature dependence in some of these works [4, 5]. Contradicting results are also reported. A correlation between the shell closure and dissipation strength is also worked out in a few cases [4].

We measured the pre-scission neutron multiplicity for the ^{30}Si+^{182,184,186}W reactions populating ^{212,214,216}Ra compound nuclei. Among the CN populated, ^{214}Ra has neutron shell closure (N=126) and others are two neutrons away on either sides. It is observed that the measured ν_{pre} values increase with increasing N/Z of the compound nuclei at all excitation energies. However the measured ν_{pre} does not show any noticeable effect of shell closure at N=126. Statistical model analysis [6] of the ν_{pre} excitation function has been performed including the collective enhancement of level density (CELD), shell correction at fission barrier and level density, K-orientation effect in fission width and dissipation. The strength of pre-saddle dissipation was fixed by reproducing the evaporation residue cross section for the ^{30}Si+^{186}W reaction and varied the strength of post-saddle dissipation according to the measured ν_{pre} values. The measured ν_{pre} values are observed to be larger than the Bohr-Wheeler predictions indicating the effect of dissipation. Strength of the deduced dissipation coefficient does not show any effect of neutron shell closure in the measured excitation energies and does not vary with the N/Z of the fissioning nuclei. Most importantly, the dissipation strength does not show any temperature dependence unlike reported earlier [5]. Emission of pre-saddle neutrons is observed to be energy independent. A substantial contribution to ν_{pre} comes from the post-saddle phase of shape evolution. CELD and K-orientation effects are also observed to be significant in these nuclei.

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Changing Picture of Energy Generation in Australia and the U.S.

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Australia is rich in fossil-fuel resources, has been the world's leading exporter of coal, and is increasing its exports of natural gas. Australia has relied heavily on burning these two fuels for supply of electricity and 12 years ago was one of the leading per-capita emitters of CO_2. A subsequent rapid increase in wind and solar generation of electricity (now 23%) has substantially reduced emissions. The country holds the world's largest proved recoverable reserves of uranium but has no nuclear-powered electricity generation capacity and exports all of its uranium production. Debate continues about whether Australia should begin to allow and even develop nuclear power as a way to combat climate change. Professor George Dracoulis advised the government on nuclear issues and published his positive views on nuclear energy [1] after the 2011 tsunami disrupted reactors at Fukushima. The U.S. has also decreased use of coal, increased natural gas consumption, and rapidly ramped up wind (but not solar) generation of electricity. Nuclear remains a substantial component (19%) in the U.S. but is decreasing as cheap natural gas forces closure of some nuclear plants. Both countries are struggling (in different ways) with the role of nuclear energy in a world with a warming climate.

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Recent and Future Underground Low-Energy Nuclear Astrophysics Experiments

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The broad field of Nuclear Astrophysics considers a wide range of stellar burning processes and nuclear interactions all feeding into the chemical evolution of our Uni-verse. In order to probe such a diverse range of nuclear processes, a complementary set of experimental and theoretical tools must be developed. The profound difficulty in measuring low-energy reactions in the stellar burning regime highlights the need for the development of such techniques. Ongoing advancements consider higher in-tensity accelerators, more robust and isotopically enriched target material and lower background interference, to name a few. Underground Nuclear Astrophysics facilities such as CASPAR, utilize natural background suppression to extend current exper-imental data to the lower energies required. New facilities around the world are coming on-line with a view to capitalizing on underground cosmic-ray suppression, each offering unique techniques and capabilities. This talk will highlight recent and future CASPAR campaigns incorporating above and below ground measurements of reactions.

Constraining the conditions for r-process nucleosynthesis via nuclear measurements at CARIBU

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The r-process, a series of rapid neutron-capture reactions in cataclysmic astrophysical events such as neutron star mergers, is responsible for the creation of roughly half of the heavy nuclei in our universe. The conditions present in these events are such that neutron-capture reactions occur on a time scale much shorter than the lifetime of the nuclei involved and the process therefore proceeds mainly through reactions on short-lived very neutron-rich nuclei, most of which having never been observed in the laboratory. Sensitivity studies [1] have looked at various scenarios for the r-process conditions and identified nuclei whose basic properties would have the largest impact on the distribution of produced nuclei. At ANL, a program centered around the ATLAS facility is aimed at improving access to these nuclei and has developed tools to measure the most critical quantities to constrain r-process scenarios.
The talk will discuss the basic nuclear physics inputs required to understand the r-process and will present the CARIBU upgrade of ATLAS that is now providing access to some key nuclei along the r-process path. Recent measurements [2] on nuclei around the N=82 and rare-earth r-process abundance peaks, focusing on Penning trap mass measurements on very exotic isotopes obtained via a new more sensitive cyclotron frequency detection method, will be discussed. Finally, a new facility, the N=126 factory, aimed at providing access to nuclei important for the formation of the heaviest r-process abundance peak, will be presented.
This material is based upon work supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

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Measurement of small and ultra-small ^{14}C samples

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In the field of geo-science applications there is an increasing demand for small and ultra-small ^{14}C measurements, e.g. for compound specific or in-situ investigations. For this purpose it is an attractive option to measure the sample material directly as CO_2 without performing the usual graphitization. At CologneAMS we are operating a dedicated Cs sputter source, HVE SO-110 B, which has been tuned for an efficient C^- extraction when CO_2 is used as sample material. In routine operation a negative ion yield of 6% is obtained. For the CO_2 injection we use an Ionplus AG gas system for which the control of the automated measurements was modified.

With this setup gaseous samples of 1-300 µg carbon can be measured. The blank level for samples with masses >50 µg is 3×10^{-15} while the detection limit of smaller samples is limited due to a contamination of typically 0.3–0.4 µg modern carbon which is mostly introduced during sample preparation work. In order to further improve the system towards the operation of ultra-small samples, special effort was spent to lower the blank level. Additionally, first test measurements of in-situ samples, prepared from 1-3 g of ^{14}C saturated CoQtz-N material and SynQtz blanks, have successfully been performed which yielded ^{14}C contents of 50k-750k atoms, with 50k atoms being the blank value.

A new spectrometer for stable isotope measurements, isoprime precisION from elementar, was acquired and will be connected to the existing gas system. This allows to measure the same sample material simultaneously with two different spectrometers and fractionation effects can be investigated more detailed.

In this contribution we report on the actual performance of the measurements and the status of the set-up.

Ion Beam Techniques for Nuclear Waste Management

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In the field of nuclear waste management, the determination of difficult to measure isotopes are important for the isotopic nuclide inventory in disposal material. Accelerator mass spectrometry (AMS) can propose a new precise and reliable way for the quantification of the radioactive material by the means of direct atom counting.
One example is the measurement of ^{14}C, which is normally measured with the liquid scintillation technique (LS). The AMS technique offers a much higher sensitivity which becomes crucial for future German clearance levels of 0.1Bq/g. In addition no pre-treatment of the samples are needed. Especially in the case of reactor concrete originated e.g. from the bio-shield of a nuclear power plant, the sample material can be directly burned in an Elemental Analyzer (EA) and the extracted CO_2 gas can be delivered to the AMS system.
For the radiological characterization of radioactive material, the reference nuclides ^{60}Co or ^{152}Eu are normally used, because they are relatively easy to measure by gamma ray spectroscopy. The disadvantages are the relatively short half-lives and in the case of reactor concrete they are produced at trace elements. Therefore, we investigated the suitability of ^{41}Ca as a reference isotope for reactor concrete. Over one hundred defined neutron irradiated heavy concrete samples, with isotopic ratios in the range of $1.0\text{x}10^{-12}$ to $1.0\text{x}10^{-9}$, were measured at the Cologne AMS system. The results confirm that AMS is very well suited for decommissioning purposes.
In addition, the technique of Projectile X-ray AMS (PXAMS) offers the opportunity to measure medium mass isotopes like ^{90}Sr, by the measurement of characteristic X-rays. We investigated the X-ray production yields for different target materials in an ion energy range of 0.35 MeV/u to 1.80 MeV/u for the determination of attainable sensitivity.

Time-Dependent Hartree-Fock Theory and Its Extensions for the Superheavy Element Synthesis

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In this contribution, recent extensions and applications of the TDHF approach for the superheavy element (SHE) synthesis will be discussed. (See, e.g., [1] for a recent review of TDHF.)

Quasifission is the predominant process that prevents the compound-nucleus (CN) formation in SHE synthesis. To understand the mechanism of quasifission is thus a crucial step towards the synthesis of the yet-unknown elements, 119, 120, and beyond. Here, we report results of systematic TDHF calculations for various projectile-target combinations ($Z_{\rm CN} = 118$, 119 and 120) at a range of incident energies. Equilibration dynamics (mass/charge/energy) in quasifission will be discussed.

Although TDHF is capable of describing the quasifission process in reactions for SHE synthesis, the CN formation after capture due to the thermal fluctuation of nuclear shapes is out of reach of the TDHF description. To evaluate the evaporation-residue formation probability, we have developed [2] a novel approach that combines TDHF with a Langevin model (fusion-by-diffusion model [3, 4]). In the latter approach, the entrance-channel dynamics are described microscopically within TDHF, which provides the initial condition for the diffusion process over the inner barrier. Implications of the TDHF+Langevin approach when applied to hot fusion reactions to synthesize the element 120 (i.e., ^{48}Ca+^{254,257}Fm, ^{51}V+^{249}Bk, and ^{54}Cr+^{248}Cm) [2] will be discussed.

Last but not least, the search for an alternative mechanism of SHE productions rather than fusion is of great importance. A seminal work by Zagrebaev and Greiner [5] initiated a revival of interest, where it has been demonstrated that multinucleon transfer (MNT) processes in deep-inelastic collisions of actinide nuclei (e.g., ^{238}U+^{248}Cm) may be useful to produce new SHEs. To explore this possibility, we have combined TDHF and TDRPA [6], where the latter incorporates fluctuations and correlations beyond TDHF, together with recent experimental data taken at the Texas A&M Cyclotron Institute. The possibility of SHE productions via MNT processes will be discussed.

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Combining activation technique and AMS for s-process measurements

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About half of the heavy elements above iron are produced in the slow neutron capture process (s-process). To understand this process, it is essential to obtain reaction cross sections under conditions corresponding to the respective astrophysical site. For the s-process, typical neutron energies are in the keV range.

Several activations with keV neutrons were performed at Karlsruhe Institute of Technology (KIT) in Germany [1]. Neutrons were produced by the reaction ^{7}Li(p,n) at the Karlsruhe 3.7 MV Van de Graaff accelerator. A quasistellar neutron spectrum could be produced, which approximates the Maxwellian distribution for kT = 30 keV.

These activations were followed by Accelerator Mass Spectrometry (AMS) at different facilities. The results were then compared to those of Time of Flight (ToF) measurements. The AMS results are systematically lower than the ToF results.

To investigate this discrepancy, a measurement at Frankfurt Neutron Source (FRANZ) in Germany [2] is planned to be performed this year. A neutron flux of about 10^8 /cm^2 /s will be provided by the reaction ^{7}Li(p,n) at the Van de Graaff accelerator. An activation using the same method as at KIT but with a different accelerator might reveal the reason for the systematic deviation between the AMS and ToF data. Subsequent AMS measurements will be performed at the 14 MV tandem accelerator of the Heavy Ion Accelerator Facility (HIAF) at the Australian National University in Canberra [3].

To complement the existing activations at kT = 30 keV, additionally several small samples are planned to be activated. Using small samples of milligramm order offers several advantages: more samples can be activated simultaneously and depending on sample positioning, different neutron energy spectra are covered within one activation. This way, a wider energy range of the s-process between about 10 and 100 keV can be reached.

In the future, FRANZ with its neutron flux up to 10^{12} /cm^2 /s will be the most powerful neutron source in astrophysically relevant energy range [2]. Activation experiments at neutron flux this high combined with the AMS technique will tremendously improve the understanding of the astrophysical s-process.

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Cosmogenic radionuclides as signatures of past Solar storm events

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This collaborative project examines the relationship between the 'Carrington Event' (CE), the largest solar storm of modern times [1], and two recently discovered cosmic radiation events of greater magnitude, the 'Miyake Events' (ME) [2, 3]. The intention is to construct cosmogenic isotope (^{14}C, ^{10}Be and ^{36}Cl) profiles across the CE, so they can be compared with similar data that have already been obtained for the ME [4]. We will use ice cores from Law Dome, East Antarctica, collected under Australian Antarctic Science awards, for the ^{10}Be and ^{36}Cl analyses. The large diameter DSS0506 ice core will permit high-resolution measurements at ANSTO of ^{10}Be and ^{36}Cl across the CE. Furthermore, we also intend to measure ^{10}Be and ^{36}Cl in the main DSS ice core across the ME. These measurements will complement existing data as both isotopes will be measured in the same ice core for each event for the first time and at high temporal resolution. New tree rings spanning the CE and ME, sourced from the Oxford Dendrochronology Laboratory, have been measured for ^{14}C at the University of Groningen at mostly annual resolution. The ultimate goal of this study is to determine whether or not all three events are manifestations of the same phenomena. A secondary goal is to provide a check on the independent DSS-main ice core chronology.

The CE of 1859 is known from geomagnetic data and contemporary records of the aurorae, which were observed as far south as the tropics [1]. The event predated ground-based neutron detectors and routine cosmogenic isotope measurement, so the intensity of the incident particle radiation is still a matter of conjecture. Indeed, this question has been thrown into sharp focus recently by new discoveries in palaeoastronomy. Analyses of natural archives (tree-rings and ice-cores) have revealed that production of the cosmogenic isotopes ^{14}C, ^{10}Be and ^{36}Cl spiked dramatically in the years 774-775 AD and 993-994 AD [2, 3, 4]. Such anomalies could only have been generated by sudden bursts of cosmic radiation. Several sources were initially proposed for the radiation, however, the consensus now is that they were driven by solar activity.

Here we discuss progress with the measurement of the cosmogenic radioisotopes and consider how the relative production rates of the cosmogenic radioisotopes may be used to substantiate a solar cause for the historical radiation events and to infer the spectral hardness of the initiating solar protons.

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Role of the surface energy in heavy-ion collisions

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A series of Skyrme interaction parameters (called SLy5sX for X=1..8) has recently been developed [1] in which there is a systematic variation of the surface energy, i. e. the coefficient a_{surf} term in the semi-empirical mass formula

$$E(A) \approx a_{vol} A + a_{surf} A^{\frac{2}{3}} + a_{curv} A^{\frac{1}{3}} + \ldots$$

An exploration of these interactions shows e.g. that the systematic variation of the surface energy leads to a conspicuous variation in the deformation energy for the fission barriers in ^{240}Pu as a_{surf} varies.

We systematically explore the properties of these SLy5sX parameters in heavy-ion collisions on the supposition that interesting results may occur since a lower surface energy means that a nucleus is more easily deformed and may be more easily polarized in the early stages of the fusion pathway, or during a glancing reaction.

Results of fusion calculations for ^{40}Ca + ^{48}Ca with the Frozen Hartree Fock approximation and with Time-Dependent Hartree-Fock show a slight but monotonic decrease in the fusion barrier height as the surface energy increases, with a barrier difference of ~200 keV between the extreme values of the surface energy.

Calculations of heavier nuclei, in which nuclear matter properties have a more dominant role than in lighter nuclei, are underway and will be presented.

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Fission Product Yield Measurements from Neutron Induced Fission of ^{235,238}U and ^{239}Pu

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Fission product yields (FPY) are one of the most fundamental quantities that can be measured for a fissioning nucleus and are important for basic and applied nuclear physics. Recent measurements [1–3] using mono-energetic and pulsed neutron beams generated using Triangle Universities Nuclear Laboratory's tandem accelerator and employing a dual fission chamber setup [4] have produced self-consistent, high-precision data critical for testing fission models for the neutron-induced fission of ^{235,238}U and ^{239}Pu between neutron energies of 0.5 to 15.0 MeV. These data have elucidated a low-energy dependence of FPY for several fission products using irradiations of varying lengths and neutron energies. This talk will present these measurements and discuss new measurements just beginning utilizing a RApid Belt-driven Irradiated Target Transfer System (RABITTS) to measure shorter-lived fission products and the time dependence of fission yields, expanding the measurements from cumulative towards independent fission yields. The uniqueness of these FPY data and the impact on the development of fission theory will be discussed.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344, and in part by the US Department of Energy, Office of Nuclear Physics, under Grant No. DE-FG02-97ER41033, and the SSAA Program of the National Nuclear Security Administration under Grant No. DE-NA0003884.

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The Heavy Ion Accelerator Facility: Research Achievements and Aspirations

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An overview of Australia's Heavy Ion Accelerator Facility (HIAF) will be presented, including a survey of the accelerator infrastructure and its capabilities, as well as the beam line instrumentation. (See Fig. 1.)

Some recent research achievements will be highlighted. Accelerator upgrades and instrumentation developments in train will be described, along with some of our aspirations for the longer-term development of the Facility and its associated research programs.

The aim will be to set the stage for the Symposium, which we hope will provide a venue for many productive exchanges of ideas between the participants and grow collaborations for future research work, particularly work at HIAF.

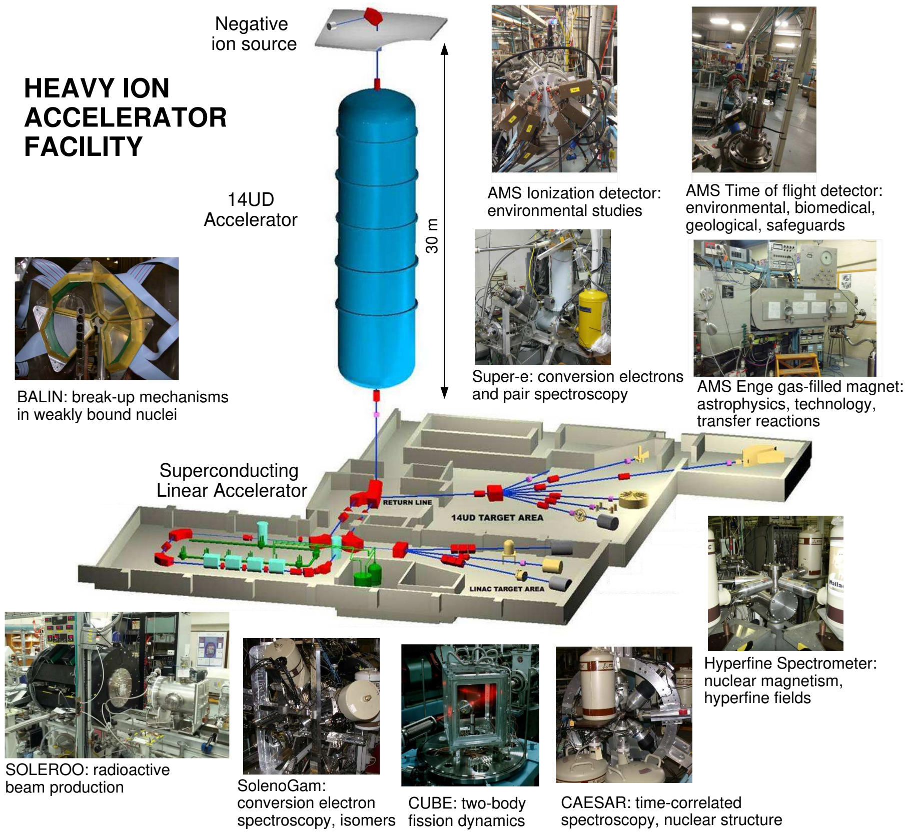

FIG. 1: The Heavy Ion Accelerator Facility and beam line instrumentation

The ANU Heavy Ion Accelerator Facility External Beam Line

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The ANU Heavy Ion Accelerator Facility provides important infrastructure for various ion-beam research opportunities. Proton therapy and other radiotherapies using massive particles, such as carbon-12 are emerging as an alternative to traditional photon radiotherapies [1]. Such particles have an energy deposition-depth profile that results in high dosage near the end of their track, with a relatively low dose elsewhere [1, 2]. The biological effect of protons and heavy ions are less well understood than those of photons. In order to study the effect of radiation on cell cultures an external beam is required as the cells cannot be placed in vacuum.

Here, we present an initial design for an external beam apparatus at the ANU heavy ion accelerator facility (HIAF). System engineering methods were used to develop the architecture of the apparatus (Figure 1) and dictated the development of a simulation framework. This framework consists of a GISCOSY beam optics simulation coupled to a Geant4 simulation that simulates the beam transition through a thin window into the air.

The spread, energy and intensity distributions of proton and carbon-12 beams were studied as a function of distance from the window, as well as the effects of alternative window materials and thicknesses. Finite element analysis is recommended to optimize the window mechanical and thermal properties. The cost of the new hardware was estimated to be approximately $12,000.

Overall, this work aims to lay the foundations of an external beam design, a simulation test framework, and the basis for a grant application for an external beam at the ANU HIAF.

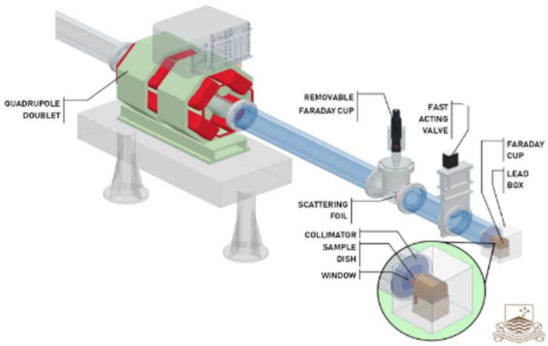

FIG. 1: The Mechanical design of the external beam apparatus, integrated with the existing beam pipe.

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AMS measurements of cosmogenic nuclide concentrations resolve mountain landscape evolution and the glacial history in the Pamir, Central Asia

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Secondary cosmic rays interact with terrestrial materials in the atmosphere and near the Earth's surface to produce cosmogenic radionuclides. The production and accumulation of cosmogenic ^{10}Be and ^{26}Al in quartz allows geologists to investigate processes of landscape evolution such as erosion, landsliding, sediment transport and deposition on time scales of thousands to few millions of years. The Pamir mountains at the western end of the India-Asia collision zone have been in the focus of geologic research since the early 2000s. While the tectonic evolution of the Pamir is increasingly well understood, the drivers of Pamir landscape evolution remain elusive. The western Pamir is characterized by an extreme topographic relief with summit and valley elevations of 6-7 km and 2-3 km, respectively; the eastern Pamir is a low-relief plateau at ~4 km. This contrast may be attributed to higher precipitation in the western Pamir driving faster river incision and erosion compared to the arid east. Alternatively, the relief may be controlled by spatially variable, tectonically forced surface uplift. Field observations suggest that Pleistocene glaciation of the Pamir was much more extensive than modern glaciation, and that glaciation had a significant impact on the evolution of the Pamir landscape.

We use cosmogenic ^{10}Be and ^{26}Al concentrations in moraine boulders, glacially polished bedrock and glacio-alluvial sediment deposits to determine the timing and extent of past glacial stages with the goal to better understand what controls landscape evolution in the Pamir. Our results indicate that early Holocene (~10 ka) glaciation was more extensive than previously thought, and that at that time the western Pamir was much more strongly glaciated than the east. The most widespread glaciation occurred at ≥200 ka covering most of the western Pamir and possibly also much of the east Pamir plateau. These results strengthen our hypothesis that the glacial history of the Pamir had a significant impact on its landscape evolution.

Systematic Study of Quasifission in ^{48}Ca-Induced Reactions

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Superheavy elements (SHEs) mark the upper boundary of the existence of atomic nuclei. The production of SHEs through the fusion of two heavy nuclei is severely hindered by the quasifission (QF) process, which results in the fragmentation of heavy systems before an equilibrated compound nucleus (CN) can be formed [1]. The QF process is the most significant limitation to SHE formation, and so a detailed understanding of this process is essential.

The heaviest elements have been synthesised using ^{48}Ca as the projectile nucleus [2, 3]. However, the use of ^{48}Ca in the formation of new SHEs has been exhausted, as the production of targets heavier than ^{249}Cf suitable for SHE production is currently not achievable. Thus, heavier projectile nuclei are required to produce new SHEs. To determine which heavier projectile should be used, an understanding of what has made ^{48}Ca so successful is crucial.

A systematic study of QF in ^{48}Ca-induced reactions with a variety of target nuclei at energies close to the Coulomb barrier is presented. Ten different target nuclei were used, ranging from the spherical ^{144}Sm, to strongly deformed nuclei, such as ^{170}Er and ^{186}W, through to the spherical ^{208}Pb. These targets allow the role of deformation in the subsequent reaction dynamics to be investigated. Moreover, the role of closed shells can also be investigated, due to the fact that the ^{48}Ca projectile and ^{208}Pb target both have full proton and neutron shells, whilst ^{144}Sm has a closed neutron shell.

To investigate the presence of QF, mass and mass-angle distributions (MADs) have been measured for all 10 reactions. The systematic changes of both the mass distributions and MADs shall be discussed in this talk, along with a novel method to investigate the probability of forming a CN through measurements of two different reactions that form the same CN.

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Study of Barrier Distributions from Quasielastic Scattering Cross Sections towards Superheavy Nuclei Synthesis

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The study of Coulomb barrier distributions is of fundamental importance in understanding heavy-ion induced fusion reactions towards syntheses of superheavy nuclei[1, 2]. Cross sections of the reactions for producing new elements are predicted to be much smaller than those for the existing elements[3–5]. They are also known to be particularly sensitive to the incident energy. One of the most direct information for determining the optimum incident energy is provided by the barrier distribution. This work aims at precisely obtaining the barrier distribution of heavy-ion induced reactions by measuring the quasielastic (QE) scattering, in order to clarify the relation between the barrier distribution and the optimum incident energy at which the evaporation residue cross section is maximized. To this end, the excitation functions of QE scattering cross sections σ_{QE} relative to the Rutherford cross sections σ_{R} for ^{48}Ca+^{208}Pb, ^{50}Ti+^{208}Pb, ^{48}Ca+^{238}U, ^{22}Ne+^{248}Cm, ^{26}Mg+^{248}Cm, ^{30}Si+^{248}Cm, ^{34}S+^{248}Cm, ^{40}Ar +^{248}Cm, ^{48}Ca+^{248}Cm and ^{50}Ti+^{248}Cm systems were measured. What is new in this method is measuring the recoiled nuclei at forward angles ($\theta \sim 0^\circ$) using GARIS. This method enables us to derive the barrier distribution for angular momentum $l \sim 0$ concerned with superheavy nuclei synthesis. The QE scattering events were well separated from deep-inelastic events by using GARIS and its focal plane detectors. The QE barrier distributions were extracted for the 10 reaction systems previously noted, and were compared to coupled-channels calculations, and were compared to evaporation residue cross-sections. The calculation results indicate that the deformation of actinoide target nucleus, the vibrational and rotational excitations of the colliding nuclei, as well as neutron transfers before contact, affect the structure of the barrier distribution. The peak of the 2n evaporation cross-section of the cold fusion reactions ^{48}Ca+^{208}Pb and ^{50}Ti+^{208}Pb – relevant to the synthesis of No (atomic number $Z = 102$), Rf ($Z = 104$) – emerged at the same energy as a local maximum of the barrier distributions. The evaporation residue cross-section of the hot fusion reactions ^{22}Ne+^{248}Cm, ^{26}Mg+^{248}Cm, ^{48}Ca+^{238}U and ^{48}Ca+^{248}Cm – relevant to the synthesis of Sg ($Z = 106$), Hs ($Z = 108$), Cn ($Z = 112$) and Lv ($Z = 116$), which are the frontier of the known superheavy nuclei – peak at an energy between experimental average Coulomb barrier height and the Coulomb barrier height for a side collision, where the projectile approaches along the short axis of a prolately deformed nucleus. This suggests that the hot fusion reactions take advantage of a compact collision geometry with the projectile impacting the side of the deformed target nucleus.

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Penetration effect on internal conversion for the 35.5 keV $M1$ *l*-forbidden transition in ^{125}Te following the EC-decay of ^{125}I

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The probability of the emission of a conversion electron is most often evaluated from the probability of photon emission and the internal conversion coefficient (ICC), α. This assumes that all nuclear structure effects are contained in the γ-ray emission probability and α only depends on atomic properties. In this case the interaction between the conversion electron and the nucleons only takes place outside the nucleus [1]. This picture is valid for most transitions, however, the atomic electron involved in the conversion process may penetrate into the nucleus and will interact with the transition charges and currents in the interior of the nucleus. The corresponding *"dynamic penetration"* matrix element M_e, which is dependent on the nuclear structure and not necessarily proportional to the γ-ray matrix element U_γ (as it was in the case of point-like nucleus), may result in anomalies in the measured ICCs. The penetration effect for magnetic transitions is often described by the penetration parameter λ=M_e/U_γ. The study of penetration effect from the measurement of ICCs provides an opportunity to test nuclear structure models by comparing the calculated λ with experiment. The measurement of λ could also be used to deduce the renormalization of g_s factor that is associated with the spin-force constant. ^{125}I is one of the commonly-used medical isotopes. To carry out low-energy electron measurements is part of our program to improve the knowledge of atomic radiations, including Auger electrons, for medical isotopes [2]. Here we report on our results from the conversion electron measurements. The measurements are essential to determine an accurate absolute yield of Auger electron emission from a radioisotope by the simultaneous measurement of conversion and Auger electrons.

In this talk we will present our high-resolution measurement of the conversion electrons from the decay of the 35.5 keV excited state of ^{125}Te using an electrostatic spectrometer at the ANU. The 35.5 keV transition is known to be a mixed $M1+E2$ transition, dominantly the $M1$ multipolarity. The penetration parameter λ=$-$1.2(6) and mixing ratio $|\delta(E2/M1)|$=0.015(2) were deduced by fitting to the available literature and the present conversion electron data. To interpret our results, we have calculated λ in the framework of particle-vibrational model. The calculated λ is not consistent with the experiment in terms of both sign and magnitude. The disagreement in magnitude stems from the underestimation of the calculated U_γ. By adopting U_γ from the experimental reduced B($M1$) transition rate to the calculations, a reasonable agreement is found between the theoretical and experimental $|\lambda|$. In order to predict the sign, we compared the sign of mixing ratio $\delta(E2/M1)$ from the angular distribution and correlation results in literature with the calculated sign of the $E2$ matrix element. This semi-empirical analysis suggests λ is negative, which is in accord with our experimental results [3].

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Shell evolution and isomers below ^{132}Sn: Spectroscopy of neutron-rich $_{46}$Pd and $_{47}$Ag isotopes

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The shell structures of atomic nuclei are nowadays known to change with the variation of the proton or neutron number, due predominantly to the monopole part of the proton-neutron interaction that includes the central and tensor forces [1]. Such a shell evolutionary behavior is expected to become pronounced when the proton-neutron imbalance is very large, leading to lost or new magic numbers [2]: For example, the conventional magic numbers N = 8, 20, and 28 disappear and the new magicity emerges at N = 16, 32, and 34, depending on the location of the nucleus in the N-Z plane. However, we don't know yet whether similar change of the shell structure can take place at the heavier conventional magic numbers N = 50, 82, and 126, which also play an important role in determining the solar abundance distribution particularly around the three prominent peaks at A ≈ 80, 130, and 195, respectively, that would result from the rapid neutron-capture (r) process.

The neutron-rich isotopes of Pd (Z = 46) and Ag (Z = 47) have attracted considerable interest in terms of the evolution of the N = 82 shell closure and its influence on the r-process nucleosynthesis. Such previously unreachable exotic nuclides have become accessible by means of in-flight fission of a high-intensity ^{238}U beam available at a new-generation RI-beam facility, the RI-Beam Factory (RIBF) in RIKEN Nishina Center [3]. In this presentation, recent spectroscopic results of Pd and Ag isotopes obtained as part of the EURICA (EUROBALL-RIKEN Cluster Array) project at RIBF [4] will be presented, with a particular focus on characteristic isomers, such as a seniority isomer in ^{128}Pd$_{82}$ [5], long-lived high-spin isomers in ^{126}Pd$_{80}$ [6] and ^{127}Ag$_{80}$, isomers with proton-hole and neutron-hole excitations in ^{125,127}Pd$_{79,81}$ [7], and low-lying β-emitting isomers in ^{123,125}Ag$_{76,78}$ [8]. The nature of these isomers will be discussed in terms of the effect of proton-neutron interactions and the resultant shell evolution below the doubly magic nucleus ^{132}Sn in the framework of shell-model approaches.

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Curious case of ^{26}Al accelerator mass spectrometry

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Accelerator mass spectrometry measurement of ^{26}Al suffers from low negative ionisation yield that often becomes the limiting factor. To counter the low Al^- yield it has been recognised that AlO^- produces negative ions much more efficiently and is a potential avenue to improve the measurement precision. When using AlO^- for the measurement there is an additional challenge to separate the interfering isobar ^{26}Mg and ^{26}Al, but this can be achieved effectively with gas-filled magnet.

However, this seemingly neat solution of using AlO^- instead Al^- for the measurement does not necessarily yield as clear cut improvements in precision as one would hope. To illustrate this point, data from conventional measurement method at ANSTO is presented and benchmarked against published data using AlO^- method.

Universal, exclusive role of seniority and shape coexistence at closed shells

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A leading issue in the study of the nuclear many-body problem is establishing concise, unified schemes of organization for excited states.

The structure of closed-shell nuclei has passed through a number of stages of evolution.

The first principle of organization was due to Maria Goeppert Mayer who recognized [1] that an even number of nucleons couple to angular momentum zero. This feature became formalized with the introduction of a short-ranged pairing force with both diagonal and off-diagonal matrix elements, resulting in Cooper pairs [2]. This led to the quasispin scheme [3], which incorporated the seniority quantum number. This has reached its epitome in the manifestation of high-j seniority structures and the description of B(E2) values expressed in closed algebraic form based on the quasispin-tensor structure of the E2 operator [4].

Following behind this development of a quasispin (seniority) scheme for organizing high-j dominated structures in singly closed shell nuclei, shape coexistence emerged as an important scheme for further organizing the structure of closed shell nuclei, especially in mid-open shell regions. This has been covered in a number of focused reviews [5]. It identifies the strongly collective structures in closed shell nuclei as resulting from deformation. It has isolated collectivity in the spherical structures as weak and limited to one-phonon strength for L = 2 and 3, and non-collective structures to (multi-j) broken-pair and one-particle-one-hole states.

A leading question that remains: “Is this organizational scheme complete?” Some recent results in closed shell nuclei will be placed into a unified scheme that suggests this question can be answered in the affirmative. In particular, the application of the seniority scheme to closed-shell nuclei dominated by medium-j and low-j orbital filling will be presented.

There appears to be a universal scheme of organization now in hand, in terms of just the above-defined concepts. Leading questions and experimental tests will be identified.

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Relevance of the Nuclear Structure of the Stable Ge Isotopes to the Neutrinoless Double-Beta Decay of ^{76}Ge

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Neutrinoless double-β decay (0νββ), the emission of two β^- particles without the emission of accompanying electron antineutrinos, has not been observed but is being sought in several large-scale experiments. 0νββ, a lepton-number-violating nuclear process, will occur only if the neutrinos have mass and are Majorana particles, *i.e.,* they are their own antiparticles. The observation of 0νββ provides perhaps the best method for obtaining the mass of the neutrino, and it is the only practical way to establish if neutrinos are Majorana particles [1].

The rate of 0νββ is approximately the product of (a) the known phase-space factor for the emission of the two electrons, (b) the effective Majorana mass of the electron neutrino, and (c) a nuclear matrix element (NME) squared. The NMEs cannot be determined experimentally and, therefore, must be calculated from nuclear structure models. A focus of many of our recent measurements has been on providing detailed nuclear structure data to guide these model calculations.

At the University of Kentucky Accelerator Laboratory (UKAL), we have performed γ-ray spectroscopic studies following inelastic neutron scattering from ^{76}Ge [2], which is widely regarded as one of the best candidates for the observation of 0νββ, and ^{76}Se, its double-β decay daughter [3]. While ^{76}Ge can be well understood from shell model calculations, ^{76}Se cannot. Moreover, the ground-state deformations of these nuclei appear to differ significantly. To better characterize this transitional region of triaxiality, studies of the lighter stable Ge nuclei have been initiated. In the case of ^{74}Ge, a great deal of information is now available, and shell model calculations explain the low-lying, low-spin structure very well [4].

The experiments, from which a variety of spectroscopic quantities were extracted, employed isotopically enriched scattering samples; the methods have been described previously [5]. From these measurements, low-lying excited states in these nuclei were characterized, new excited states and their decays were identified, level lifetimes were measured with the Doppler-shift attenuation method, multipole mixing ratios were established, and transition probabilities were determined.

This material is based upon work supported by the U.S. National Science Foundation under grant no. PHY-1606890.

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