Workshop on Beta-delayed neutron emitters: evaluation and measurements

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Book of Abstracts

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Decay spectroscopy of fission products including beta-delayed neutron emission at the HRIBF (Oak Ridge)

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The decay studies of fission products performed at the Holifield Radioactive Ion Beam Facility operating between 1996 and 2012 at Oak Ridge will be presented. The published results include beta-delayed neutron branching ratio measurements for several Cu, Zn and Ga isotopes. New spectroscopy measurements reaching up to 79Cu, 83Zn, 86Ga, 86Ge and 87As will be discussed. The selected results from the studies involving a hybrid system of 3He counters and beta-gamma set up as well as recent campaigns with Modular Total Absorption Spectrometer and VANDLE neutron time flight detector will be presented.

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Welcome

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Introductory remarks

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A new IAEA CRP proposal: Development of a reference database for Beta-delayed neutron emission evaluation

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Evaluation of beta delayed neutron emission- Now or never

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Past beta-delayed emission evaluations

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Beta-delayed neutron emission in fission products had already been discoverd a few months after fission itself. Ever since then, this decay mode has been studied intensively, as the data are essential input values for technical applications as fission reactors. Accordingly, there exists qite a lot of compilations and evaluations dealing with asüects of this decay mode as the emission probabilities or energy spectra. But these evaluations deal nearly exclusively with properties of neutron-rich nuclei obtained in neutron-induced fission. With the advent of radioactive beam facilities these decays can now be studied also in light and heavy nuclei. Up till now, no evaluation is available for these isotopes. In addition, new data on the delayed emission of charged particles and delayed fission will become available, so that a future extension of the evaluation ought to be considered.

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Status of beta-delayed neutron measurements and evaluation in low-mass region.

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Based on Audi's 2011 interim mass adjustment file, lists of all the known nuclides have been extracted for which B-N, B-2N and B-3N decays are possible. Those for which measurements exist are indicated in tabular files as well as interactive chart of nuclides. Evaluation of B-N and B-2N data for about ten nuclides in the lowest mass region will be presented.

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Systematics of beta-delayed neutron emission probabilities

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We explore the systematics of beta-delayed neutron emission probabilities both globally and in regions relevant to applications, such as decay heat calculations. Traditionally, correlations were sought by investigating the P$nvalueasafunctionoftheQvalueofthedecay(orsomerelationinvolvingQ).Here,wep
delayedneutrondecay,Q{\beta n}.SucharelationcanbeusedtopredictP_nvaluesforcaseswherethehalf−
lifeisknownandcouldbeofrelevancetor−processcalculationsorpredictionsofadvancedfuelcycles.Correlationsch
of − principlecasein^{138}$I will be given.

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From Pn values to nu-bars

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We have calculated the average number of delayed neutrons per fission (nu-bars) for neutron induced fission on a number of actinide targets. Additionally, we have calculated the neutron energy spectra and the so-called six-group parameters. The influence of the Pn and T1/2 data on these calculations will be discussed.

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The TRIUMF-ISAC beta-decay program and future possibilities for study of beta-delayed neutron emitters

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Modern radioactive-beam facilities are capable of producing intense sources that are ideal for beta-decay studies. At the TRIUMF-ISAC facility, we have a strong program of nuclear structure studies utilizing beta-decay and the 8pi spectrometer. Part of our program have examined systems close to stability, concentrating on very-high-statistics measurements, while another component of the program examines nuclei far from stability. With 20 Compton-suppressed HPGe detectors, an array of 20 plastic scintillators for beta-particle tagging, 5 Si(Li) detectors for conversion electrons, a fast-plastic scintillator and 10 BaF2 or LaBr3 detectors for lifetime measurements, a moving-tape collector, all coupled to a high-precision and high-throughput data acquisition system, the 8pi spectrometer is currently the world's most sensitive array dedicated to beta-decay studies. We are currently constructing the GRIFFIN array, based on 16 large-volume clover detectors, that will replace the 8pi spectrometer and improve the gamma-gamma coincidence efficiency by a factor of 300 at 1 MeV.
A new device is also currently being constructed, the DEuterated Scintillator Array for Neutron Tagging (DESCANT), that covers a 1pi sr solid angle and will be coupled to GRIFFIN. This will enable studies of beta-delayed neutron emitters to an unprecedented level of sensitivity. Combined with new capabilities at TRIUMF-ISAC for producing neutron-rich beams, with the current actinide targets on the proton beam line or the new ARIEL electron accelerator and a photo-fission source, a program studying beta-delayed neutron emitters envisioned. This presentation will focus on the present and future experimental capabilities for such studies.

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Plans for beta decay experiments at RIBF

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The beta-decay study of neutron rich nuclei is a priority of the Radioactive Ion Beam Factory (RIBF). The unique capabilities of RIBF to produce and identify extremely neutron rich nuclei produced by in-flight fission of a 345 MeV/nucleon 238U beam has been proven for example in Ref. [1], and the first successful beta-decay experiment in the 110Zr regions was performed in 2008 with 238U beam at an average intensity of 0.3 pnA [2]. In this contribution I will briefly report the current status of the 238U beam, the detector capability, and the near-future plans for beta-decay experiments at RIBF. In particular, I will discuss the current status of the beta counting system, which is relevant for the future beta-delayed neutron emission campaign prospected at RIBF.
References [1] Onishi et al., Journal of the Physical Society of Japan, 79, 073201(2010). [2] Nishimura et al., PRL 106, 052502 (2011).

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Ongoing and planned β-delayed neutron measurements with BELEN for astrophysics, nuclear structure and reactor technology

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A new neutron counter BELEN (BEta deLayEd Neutron) is being developed within the DESPEC-NUSTAR experiment for the future FAIR facility by the UPC-Barcelona, IFIC-Valencia and GSI-Darmstadt/Giessen U. collaboration. Meanwhile the detector is being employed at several installations for the study of beta-delayed neutron emission probabilities Pn.. The commissioning of the detector and first experiment was performed at the IGISOL separator of JYFL-Jyvaskyla using the Penning trap to produce pure isotopic beams of nuclei relevant for reactor technology and nuclear structure studies. An enhanced version of the detector has been used at an experiment performed at the GSI fragment separator FRS to study delayed neutron emitters of astrophysical interest close to the r-process path regions leading to the 2nd and 3rd abundance peaks. The analysis of these experiments is still ongoing. New experiments are already scheduled at JYFL of interest in technology and astrophysics and new proposals are being discussed. The detector is currently being upgraded and a future enhancement thanks to the collaboration of JINR-Dubna is expected. A description of the detector and of the ongoing work will be presented.

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ENDF/B-VII.1 library availability with new P_n values

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The decay sub-library for ENDF/BVII.1 was recently released at the NNDC. This incorporates new data, whenever available, updated Q values, and the latest electron conversion calcuations. Considerable effort was spent reviewing each decay set, and benchmarking the performance of the library which contains data for 3817 isotopes including isomeric states. For beta-delayed neutron emitters, the experimental neutron spectra are obtained from ENDF/B-VI.8 and are combined with the beta spectra from ENSDF. Experimental measurements of neutron spectra are difficult and sometimes not available. In such cases, a micro-macrscopic (QRPA) theory of the beta-decay strength function is used, and neutron and gamma-ray spectra are calculated using the statistical Cascading Gamma Multiplicity Model (CGM) of continuous gamma, beta, and neutron spectra. The library contains the latest up-to-date P_n values taken from experimental data when available and from the CGM calculations otherwise. Likewise, lifetimes are from experimental data when available; otherwise systematic values are used. In the area of r-process nuclei and reactor fission products where experimental data are often limited, the CGM calculations had some interesting predictions, a few of which will be shown. The entire library is available for public use and how to access it is demonstrated.

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Beta-delayed neutron spectroscopy using trapped radioactive ions

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Reliable measurements of beta-delayed neutron properties can be performed with precision by confining radioactive ions in an ion trap. When a radioactive ion decays in the trap, the recoil-daughter nucleus and emitted particles emerge from the <1 mm^3 trap volume without scattering and propagate unobstructed through vacuum. These properties allow the momentum and energy of the emitted neutron to be precisely reconstructed from the nuclear recoil. Spectroscopy of beta-delayed neutrons can be performed with high efficiency, energy resolutions approaching

3%, and virtually no background. By loading neutron-rich fission fragment beams from the Californium Rare Isotope Breeder Upgrade (CARIBU) facility at Argonne National Laboratory into a specially-designed radiofrequency quadrupole ion trap system, a program of beta-delayed neutron spectroscopy in this largely unexplored region of the nuclear chart can be performed. This recoil-ion technique will be described and the status of the current campaign and future prospects for the CARIBU experiment will be discussed.
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Importance of fully microscopic approach to delayed neutron emission

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Incomplete and inadequate decay data for the short-lived fission products restrict applicability of summation codes in estimating the reactor decay heat for the short cooling times or deriving the absolute delayed neutron yields. The beta-decay properties of a much broader set of the very neutron-rich nuclei are of need for the astrophysical r-process modeling. The vast majority of these nuclides are experimentally unknown. Thus, a reference database of evaluated half-lives and beta-delayed neutron emission rates should include reliable theoretical predictions. The very neutron-rich nuclei present a unique laboratory for exploring nuclear structure under extreme conditions. Recently the half-lives and delayed neutron branchings of Zn to Ge isotopes with N>50 have been measured for the first time at HRIBF ORNL using radioactive beam purification and tagging technique with efficiency calibrated [U+03D2]-detectors [1]. The experiments have shown that the reference global GT model [2], as well as semi-statistical GT+FF models [3,4] fail to reproduce the newly measured half-lives of neutron-rich nuclei near and beyond the shell closures at Z=28, N=50. Thus, the RIB experiments offer a stringent test for the models aiming at the ground state and β-delayed properties. In particular, beyond the most neutron-rich doubly-magic nucleus 78Ni, the appropriate model should account for the observed sub-shell closure at N=58 [5], related weakening of the 78Ni core and crossing of the p2p3/2 and p1f5/2 levels which causes an inversion of the ground-state spin-parities [6]. Such a drastic change of the single-particle pattern should be properly taken into account in β-delayed emission studies. Moreover, for the N>50 nuclides the first-forbidden (FF) decays start to compete with the Gamow-Teller (GT) decays [5]. The new data [1] give a possibility to verify the different predictions and extend the fully microscopic beta-decay model [7]. The self-consistent DF+CQRPA approach [7] augmented by blocking describes properly the ground state properties of the parent and daughter isobaric companions. A reasonable agreement with both known and new experimental half-lives [4] gives some confidence in extrapolation to more exotic nuclides. A stabilization of the half-lives near new sub-closure of N=58 is predicted which may facilitate the measurements in more exotic Ga isotopes with A>85. Importantly, the new data support the predicted reduction of the delayed total and multi-neutron emission probabilities in the regions of 78Ni and 132Sn due to the high-energy FF transitions [7]. A significant redistribution of the r-process abundances is also found from the new calculations by R. Surman using DF3a+blocking set of the half-lives. Shorter half-lives of less exotic members of the isochains (cf. to the standard half-lives by [2,3]) together with the longer for the more exotic members trap material in the first abundance peak while depleting the second and increasing the abundances of A>140 isobars. The work is supported by the JIHIR, ORNL and IN2P3-RFBR agreement 110291054.
[1] M. Madurga et al., Phys.Rev.Lett. ,submitted 2012. [2] B.Pfeiffer et al., Ann.Nucl. Energy 41, 39 (2002). [3] P. Moeller et al., Phys.Rev. C67, 055802 (2003). [4] T. Tachibana et al. Prog. Theor. Phys. 84, 641 (1990). [5] J.A. Winger et al., Phys.Rev. C81, 044303 (2010). [6] K.T. Flanagan et al., Phys.Rev.Lett. 103, 142501 (2009). [7] I.N. Borzov, Phys.Rev. C67, 025802 (2003); C71, 065801 (2005).

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Discussion