Japan Atomic Energy Agency – Advanced Science Research Center

Research Group for Reactions involving Heavy Nuclei

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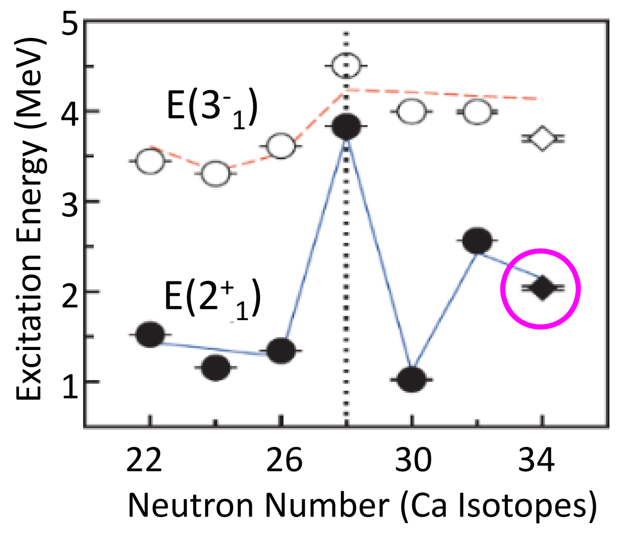
Research Activity Summary for Fiscal Years 2010-2014

(2/2) Exotic Nuclear Structure and Decays, and Fukushima Issues

Nuclear Structure Calculations

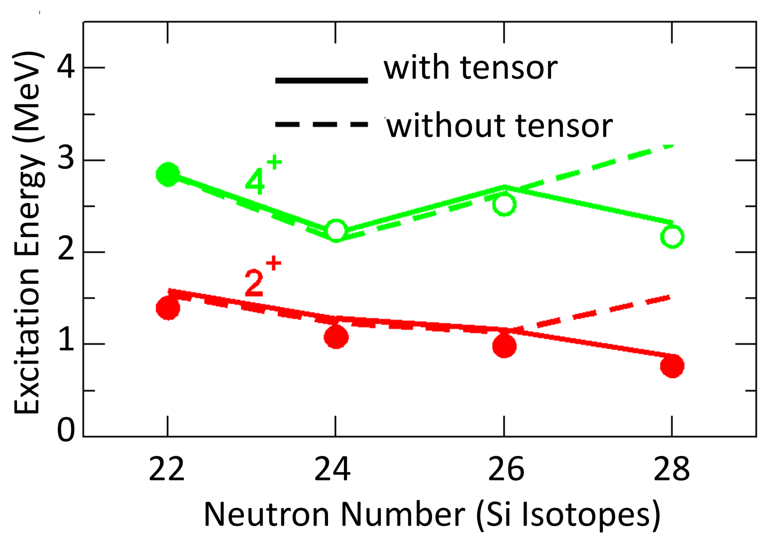
As well as playing a dominant role in fission, nuclear-structure is key to our fundamental understanding of the nucleus. Recent experimental results from radioactive-ion-beam facilities have revealed **a drastic change in shell structure** in going **from stable to exotic nuclei**. By proposing a **unified effective interaction which can account for shell evolution** [a], this group greatly contributed to clarify its underlying mechanism. **Large-scale nuclear-structure calculations** based on the shell model were developed and carried out for exotic nuclei. These calculations permit direct comparison with experimental data and help to ascertain the origin of shell evolution [a,b].

a)



Comparison between calculated (lines) and experimental (symbols) systematics of the **energy levels in calcium isotopes**. The high-lying 2^+_1 level measured ^{54}Ca in 2013 **confirms the *N*=34 magic number** predicted by our group.

b)



Comparison between experimental (circles) and calculated (lines) **2^+_1 and 4^+_1 levels in silicon isotopes**. The **breakdown of the conventional *N*=28 magic number** is reproduced only using the interaction which includes the tensor force. The large deformation of ^{42}Si (*N*=28) is due to the **tensor-force-driven Jahn-Teller effect**.

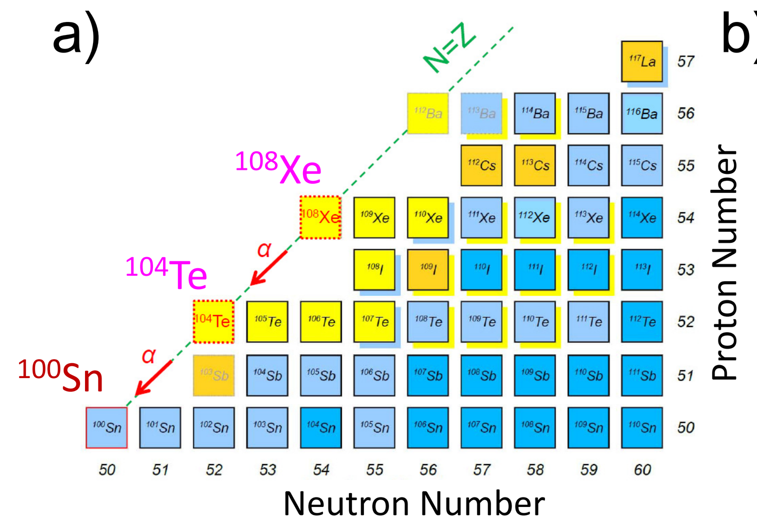
[Expt.] D. Steppenbeck … Y. Utsuno *et al., Nature* **502**, 207 (2013)
[Calc.] Y. Utsuno *et al., Prog. Theor. Phys. Suppl.* **196**, 304 (2012)

Y. Utsuno *et al., Phys. Rev. C* **86**, 051301(R) (2012)
Y. Utsuno *et al., Phys. Rev. Lett.* **114**, 032501 (2015)

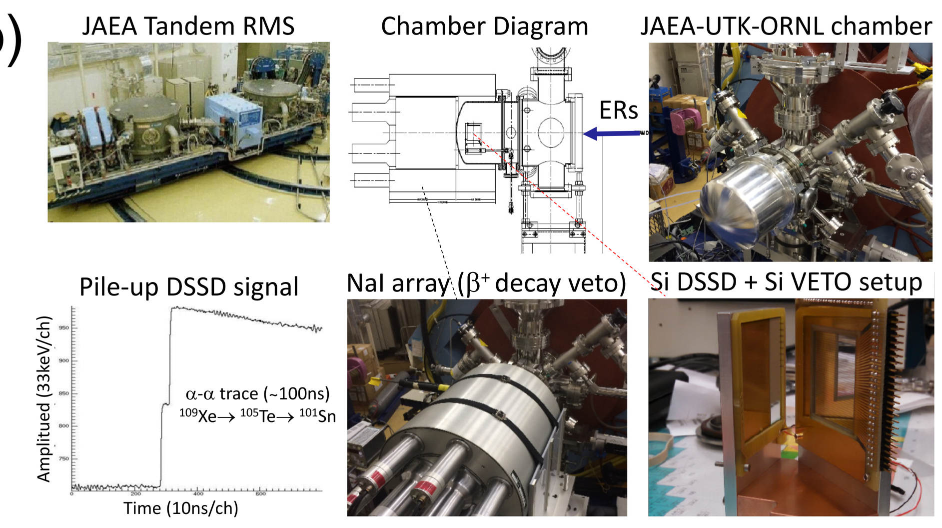
'Superallowed' ^{104}Te->^{100}Sn α Decay

^{100}Sn is the heaviest possible **doubly-magic nucleus with equal numbers of protons and neutrons** (*N*=*Z*=50). The **shell effects on the binding energies** active in the proximity of ^{100}Sn create the lightest-mass β-decay island of the nuclear chart [a]. The large overlap of nucleons occupying the same orbits is **predicted to strongly enhance the α preformation probability**, making the **^{104}Te→^{100}Sn α decay the fastest among all nuclei (~50 ns)**. We are carrying out a dedicated spectroscopy program at the JAEA Tandem Recoil Mass Separator (RMS) with the goal to observe this predicted "superallowed" α decay.

a)



b)

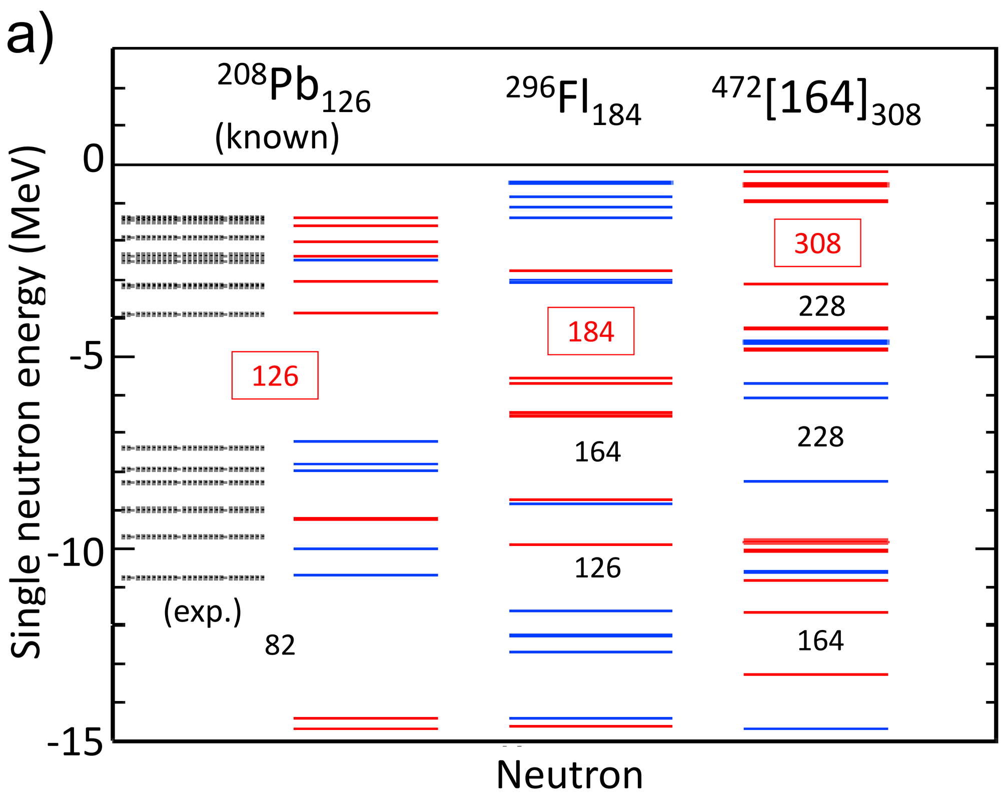


α-decaying isotopes appear in light yellow in [a]. We access this region of the chart via fusion-evaporation reactions with stable beams and targets, using the **JAEA RMS** [b] **to select** among the evaporation residues **the channel of interest**. **Proof-of-principle experiments**, carried out in 2014, **showed an excellent performance** of our setup. With the **digital electronics** from UTK/ORNL, **fast decay chains produced with only tens of nanobarn cross section**, such as ^{109}Xe[13 ms] →^{105}Te[620 ns]->^{101}Sn (shown in [b]) were **implanted onto our Si DSSSD detector and measured** at the focal plane. A long experiment to **hunt for the ^{108}Xe->^{104}Te->^{100}Sn double-α chain will be run in 2015**. This research program is **funded by REIMEI** and carried out **in collaboration with colleagues from UTK/ORNL (USA), Univ. of York (UK), GSI (Germany)**, and other international institutes.

Limits of nuclear existence

One of the fundamental question of nuclear physics is related to understanding **which nuclei can exist** as bound systems. Using mean-field calculations, we calculated a **super-heavy single-particle shell closure for the nucleus $^{472}164_{308}$** [a] predicted to be the **heaviest possible doubly-magic** nucleus. In [b] Chart of Nuclides (2010), where unknown masses have been calculated using the KTUY mass formula.

a)



H. Koura and S. Chiba, *JPSJ* **82**, 014201 (2013)

b)

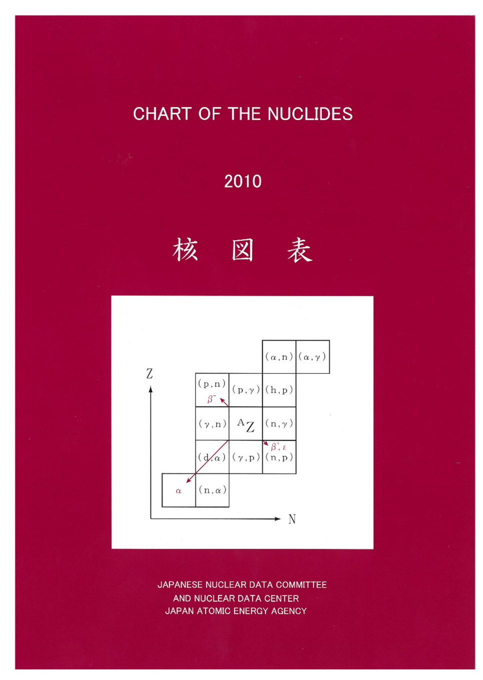
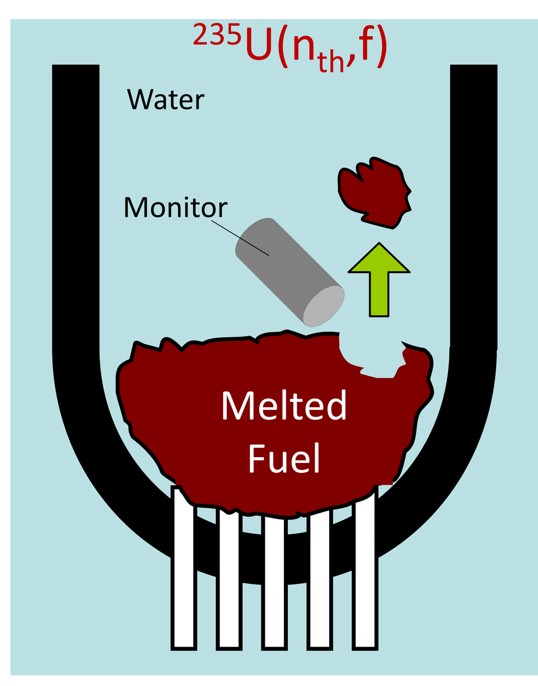


Chart of the Nuclides, Compiled by T. Tachibana, H. Koura and J.Katakura, JNDC and Nuclear Data Center, JAEA (2010). http://wwwndc.jaea.go.jp/CN10/

Fukushima-related Measurements

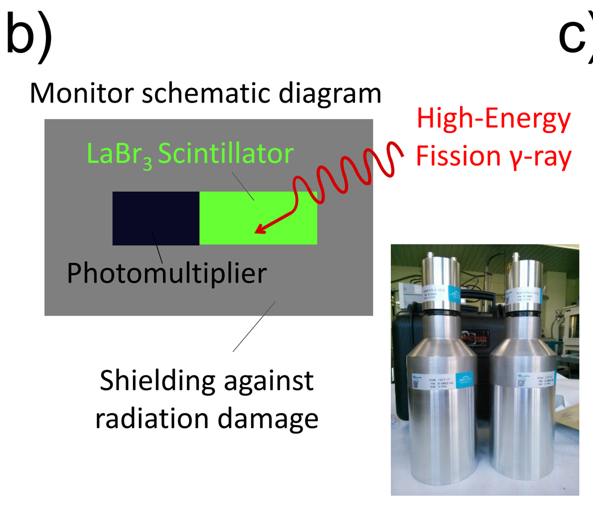
One of the problems to overcome in order **to remove the melted fuel** from the damaged Fukushima reactors [a], is to carry out the operation **without reaching criticality**. This requires to detect the changes in the fission rate following the displacement of fuel. We propose a **new surveillance monitor** [b], based on the **detection of high-energy γ rays** [c] which would easily penetrate the monitor protective shielding.

a)

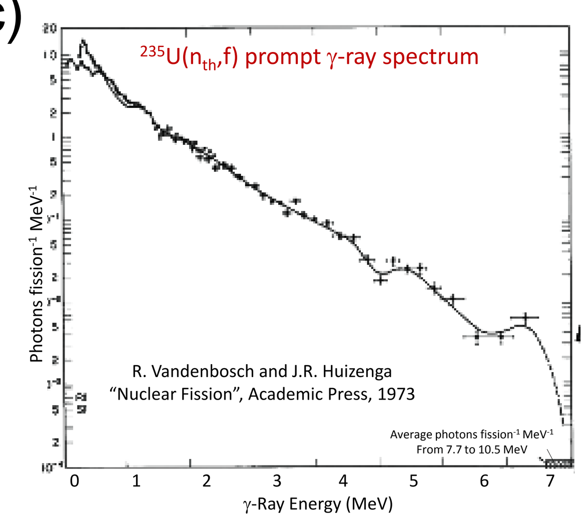


Schematic diagram of damaged reactor core and surveillance monitor

b)



c)

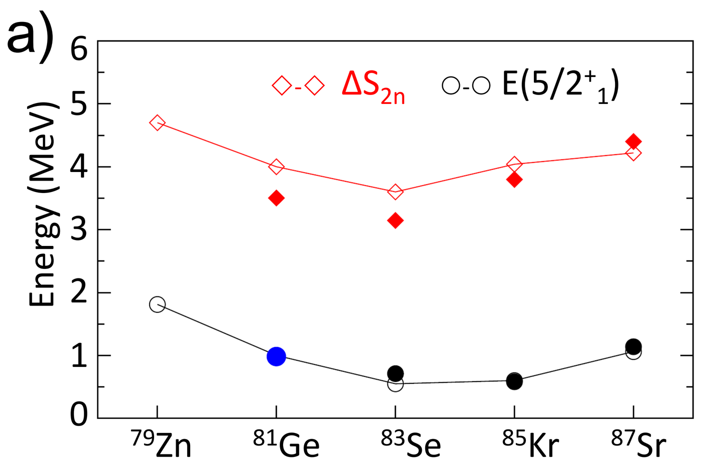


The spontaneous fission of ^{252}Cf shows an increase in γ-ray rates for E > 12 MeV, attributed to the **GDR resonance in fission fragments**. Such **high-energy background-free γ rays would make excellent probes of the fission rate**. In order **to study the γ-ray spectrum of $^{235}U(n_{th},f)$** – currently only known up to ~10 MeV [c] – to energies up to 20 MeV, we developed a setup based on our $LaBr_3$ detectors and a new chamber. Preparatory tests have been carried out at the **KURRI research reactor** in Kumatori, Japan. Additional measurement are planned at the **ILL research reactor** in Grenoble, France. This work is supported by MEXT funding.

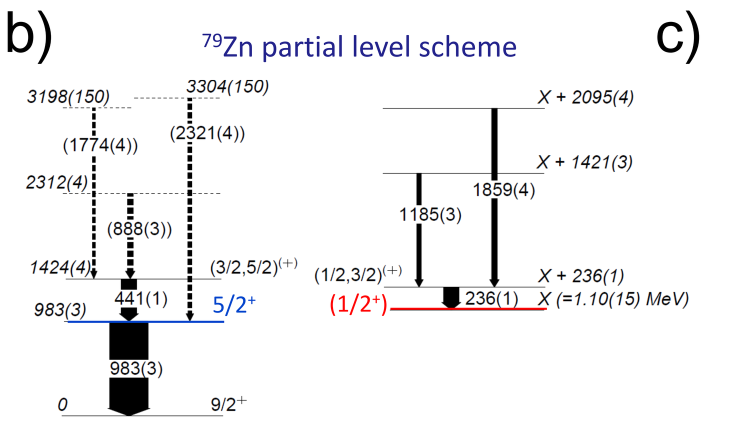
Single-particle properties near exotic doubly-magic nuclei

In order to test and guide theoretical developments in the understanding of nuclear-structure evolution, it is of paramount importance to obtain **spectroscopic information on isotopes neighbouring *exotic* doubly-magic nuclei**, such as ^{78}Ni, ^{100}Sn and ^{132}Sn. **Single-nucleon transfer reactions** are one of the best tools to populate single-particle properties. Our group has measured two such isotopes, **^{79}Zn** [a,b] and **^{131}Sn** [d], with the reactions ^{78}Zn(d,p)^{79}Zn and ^{132}Sn(d,t)^{131}Sn, using radioactive beams at REX-ISOLDE, CERN (Switzerland) and at the ORNL (USA). The experiments were performed respectively using the coupled T-REX-Miniball Si+HPGe Arrays [c] and SuperORRUBA [e].

a)

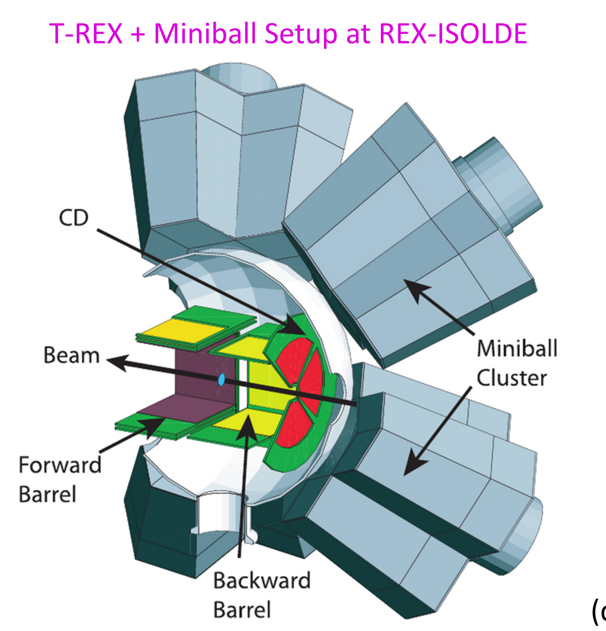


b)



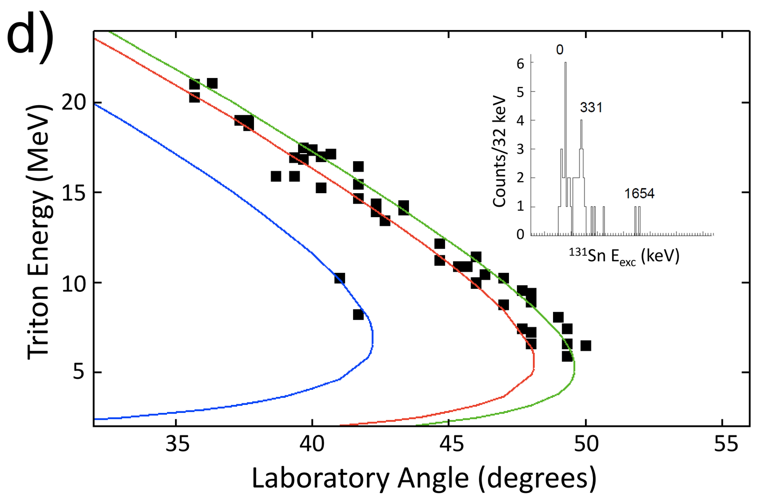
R. Orlandi *et al.*, *Phys. Lett. B* **740**, 298 (2014)

c)



[a] Energy of 1st excited 5/2⁺ state (○●) and N=50 shell gap size (◇◆) for N=49 isotopes neighbouring ^{78}Ni. The **excellent fit** obtained **with** state-of-the-art **Large-Scale Shell-Model Calculations** (empty symbols), support the picture of a very **robust doubly-magic ^{78}Ni**. [b] Partial level scheme of ^{79}Zn, deduced from the combination of proton and γ-ray spectroscopy. The 5/2⁺-state energy deduced in this work appears in blue in [a].

d)



R. Orlandi *et al.*, To be submitted for publication.

e)

(d) **Tritons detected** in one of the 8 SI telescopes of **SuperORRUBA,** in the study of the ^{132}Sn(d,t)^{131}Sn reaction. The points fit the kinematic lines of the $d_{3/2}$, $s_{1/2}$ and $d_{5/2}$ neutron-hole states. The inset shows the corresponding excitation energy spectrum. The analysis of the full data will permit the first determination of the spectroscopic factors of these key states.