

Japan Academy Prize to:

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for “The Discovery of a $Z = 113$ Superheavy
 Element”

Outline of the work:

Prof. Kosuke Morita, leading a research team at RIKEN, discovered a new superheavy element with atomic number $Z = 113$. The experiment was conducted by bombarding a target ^{209}Bi with a ^{70}Zn projectile. Then, the radioactive elements of $Z = 113$ were separated and collected using the electromagnetic method and their successive alpha decays were traced in solid-state detectors with high precision. The Zn beam was extracted from the RIKEN heavy-ion linear accelerator (RILAC), and the forward-emitted superheavy nuclei after nuclear fusion reactions were selected for detection. For this purpose, a gas-filled recoil ion separator (GARIS) was developed. This device allowed the successful separation of ultra-low-intensity superheavy nuclides from a large amount of unnecessary intense reaction product. Candidates of superheavy isotopes were implanted into position-sensitive semiconductor detectors and the obtained position and timing information of each event, in addition to precise measurements of the transition energies, enabled the determination of the mass number (A) and lifetime of each alpha decaying state in a successive alpha cascade. The birth probability of each alpha-decay chain was observed to be extremely small, therefore, the observation occurred approximately only once per year. Nevertheless, the high efficiency of GARIS helped in detecting the superheavy elements with an almost completely suppressed background. In addition, very high-intensity beam acceleration was developed, which was a key element for the success of the experiment. All of these developments, from the initial plan to the commitment and analysis over a decade, were made possible by the excellent leadership of Prof. Morita and the cooperation and painstaking efforts of his team members.

The highlight of this experiment is the high efficiency and selectivity of GARIS in detecting very rare but significant events from a huge background. This experiment employed the so-called cold-fusion method, i.e., bombarding the target Z_t with a Z_p projectile at an energy low enough to allow only one neutron to escape the fusion reaction and to suppress the emission of charged particles such as protons and alpha particles; this simplifies the assignment of the element identification to $Z = Z_p + Z_t$. The limitation of this method is the extremely small cross section of the final superheavy nuclei. Nevertheless, the RIKEN team decided to use the cold-fusion method and challenged the difficulty of obtaining the ultra-low intensity by increasing the efficiency of GARIS and the intensity and stability of the accelerator.

Despite the possibility of an extremely low yield, the cold-fusion method has several unique characteristics, namely, no ambiguity in assigning Z , and enabling the alpha-decay chain to reach an anchor nucleus, where it is connected to a known isotope. This allows an unambiguous establishment of the genetic relation.

The RIKEN group observed three robust chains in 2004, 2007, and 2012, all of which were assigned to be the isotope possessing $Z = 113$ and $A = 278$. This isotope was confirmed to decay $(113, 278) \rightarrow (111, 274) \rightarrow (109, 270) \rightarrow (107, 266) \rightarrow (105, 262)$. The decay stops at the known isotopes ^{266}Bh and ^{262}Db , which are

produced by different reactions (cross reactions). Even though a tremendous effort was made to increase the intensity of the accelerated beam, it took approximately 600 days over nine years of accelerator beam time to observe the above-mentioned three key events. This resulted from the tireless efforts of the research team.

Simultaneous to these RIKEN experiments, a series of experiments were conducted by a research team at Dubna, Russia, using the hot-fusion method, which involves using high-energy projectiles of ^{48}Ca to cause two- to five-neutron emissions. This method has the advantage of larger cross sections for more reaction products but a possible charged-particle emission that would lead to misidentification of the proton number of the residual nuclei cannot be avoided in this method. The Dubna group claimed the discovery of a few $Z = 113$ isotopes (but with different neutron numbers) at nearly the same time as the first report of the RIKEN isotope but none of them was recognized as being connected to existing nuclei. Later, the same group observed new isotopes with $Z = 115$ and 117 using cross reactions.

Based on the assessments of the joint working group of the two international unions of chemistry and physics (IUPAC and IUPAP), which is a unique body that evaluates and recognizes the discovery of new elements, IUPAC announced on December 30, 2015 that the RIKEN research team from Japan has fulfilled the criteria for discovering a new element $Z = 113$ and will be invited to propose a permanent name and symbol for the element. This is the consequence of the RIKEN's strategy to concentrate on the very rare cold-fusion reaction, which has an extremely low yield but provides a definite identification.

The search for new elements is an experimental trial to answer the question of where the upper limit of the atomic number, limit of all the substances. It also opens the door to intriguing questions such as the similarity of elements in the same row of the periodic table. The physical and chemical properties of superheavy elements will reflect the knowledge of the structure and properties, such as magic numbers and relativity effects, at the extreme limits of an atomic nucleus. The discovery of $Z = 113$, together with the following elements, will open the door to the next row, i.e., the eighth row, of the periodic table.

In summary, Prof. Morita led a group at RIKEN to carry out a series of experiments leading to the discovery of the $Z = 113$ superheavy element and thus established himself as an internationally recognized scientist. He and his group were given the GSI Exotic Nuclei Community Membership Award (2005), the Nishina Memorial Prize (2005), the Inoue Prize for Science (2006), and the 11th Outstanding Paper Award of the Physical Society of Japan (2006). In 2016, Prof. Morita's group was invited to propose the name and symbol of the 113th element by the IUPAC-IUPAP committee.

List of Publications

- [1] K. Morita, K. Morimoto, D. Kaji, H. Haba, E. Ideguchi, J. C. Peter, R. Kanungo, K. Katori, H. Koura, H. Kudo, T. Ohnishi, A. Ozawa, T. Suda, K. Sueki, I. Tanihata, H. Xu, A. V. Yeremin, A. Yoneda, A. Yoshida, Y.-L. Zhao, T. Zheng, S. Goto, and F. Tokanai, *Journal of Physical Society of Japan* **73** (2004) 1738-1744. 'Production and Decay Properties of $^{272}111$ and its Daughter Nuclei'.
- [2] K. Morita, K. Morimoto, D. Kaji, T. Akiyama, S. Goto, H. Haba, E. Ideguchi, R. Kanungo, K. Katori, H. Koura, H. Kudo, T. Ohnishi, A. Ozawa, T. Suda, K. Sueki, H. Xu, T. Yamaguchi, A. Yoneda, A. Yoshida, and Y.-L. Zhao, *Journal of Physical Society of Japan* **73** (2004) 2593-2596. 'Experiment on the Synthesis of Element 113 in the Reaction $^{209}\text{Bi} (^{70}\text{Zn},n)^{278}113$ '.
- [3] K. Morita, K. Morimoto, D. Kaji, T. Akiyama, S. Goto, H. Haba, E. Ideguchi, K. Katori, H. Koura, H. Kikunaga, H. Kudo, T. Ohnishi, A. Ozawa, N. Sato, T. Suda, K. Sueki, F. Tokanai, T. Yamaguchi, A. Yoneda, and A. Yoshida, *Journal of Physical Society of Japan* **76** (2007) 045001. 'Observation of Second Decay Chain from $^{278}113$ '.

- [4] K. Morita, K. Morimoto, D. Kaji, T. Akiyama, S. Goto, H. Haba, E. Ideguchi, K. Katori, H. Koura, H. Kudo, T. Ohnishi, A. Ozawa, T. Suda, K. Sueki, F. Tokanai, T. Yamaguchi, A. Yoneda, and A. Yoshida, *Journal of Physical Society of Japan* **76** (2007) 043201. ‘Experiment on Synthesis of an Isotope $^{277}112$ by $^{208}\text{Pb} + ^{70}\text{Zn}$ Reaction’.
- [5] K. Morita, K. Morimoto, D. Kaji, H. Haba, K. Ozeki, Y. Kudou, N. Sato, T. Sumita, A. Yoneda, T. Ichikawa, Y. Fujimori, S. Goto, E. Ideguchi, Y. Kasamatsu, K. Katori, Y. Komori, H. Koura, H. Kudo, K. Ooe, A. Ozawa, F. Tokanai, K. Tsukada, T. Yamaguchi, and A. Yoshida, *Journal of Physical Society of Japan* **78** (2009) 064201. ‘Decay Properties of ^{266}Bh and ^{262}Db Produced in the $^{248}\text{Cm} + ^{23}\text{Na}$ Reaction’.
- [6] K. Morita, K. Morimoto, D. Kaji, H. Haba, K. Ozeki, Y. Kudou, T. Sumita, Y. Wakabayashi, A. Yoneda, K. Tanaka, S. Yamaki, R. Sakai, T. Akiyama, S. Goto, H. Hasebe, M. Huang, T. Huang, E. Ideguchi, Y. Kasamatsu, K. Katori, Y. Kariya, H. Kikunaga, H. Koura, H. Kudo, A. Mashiko, K. Mayama, S. Mitsuoka, T. Moriya, M. Murakami, H. Murayama, S. Namai, A. Ozawa, N. Sato, K. Sueki, M. Takeyama, F. Tokanai, T. Yamaguchi, and A. Yoshida, *Journal of Physical Society of Japan* **81** (2012) 103201. ‘New Result in the Production and Decay of an Isotope, $^{278}113$, of the 113th Element’.