RIKEN: The 100th Anniversary of a Major Research Organization of Japan — The Day the 113th Element Was Born

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December 1, 2016. On this day, a press conference took place in a Fukuoka city hotel that deserves to go down in the history of science in Japan. The day before, at the Institute of Physical and Chemical Research (known as RIKEN) in Wako, Saitama Prefecture, the acceptance of an official name for a new chemical element artificially created in Japan was announced. Its name was nihonium, its symbol Nh, and its atomic number 113.

The periodic table is an organizational system for the elements, and is to science what the alphabet is to the English language. But until recently, the elements that fill the table were all officially discovered in the countries of Europe and North America, and none in Japan.

In fact, in 1908 a Japanese had discovered the forty-third element and proposed the name nipponium for it. The fourth president of the Tohoku Imperial University, Ogawa Masataka, claimed that an element he had found in thorium ore was a "new element." Ogawa, however, was not able to obtain proof of his discovery and the "legendary element" of nipponium disappeared from the history of science. Later, thanks to verification by Yoshihara Kenji (emeritus professor at Tohoku University), the new element was confirmed to be one located directly underneath the forty-third element in the periodic table, the then unknown seventyfifth element, rhenium. But due to factors such as a lack of accurate analytical equipment, the honor of the first element discovered by Japanese scientists slipped away.

Yet, 108 years after the first mention of this legendary element nipponium, Japan was able to add the new element of "nihonium" to the periodic table, not a list of all the elements but a fundamental tool of chemistry and physics. This enormous achievement has a cultural significance equal to adding an extra letter to the 26 of the alphabet, and had been eagerly awaited by the Japanese scientific community for over 100 years.

The press conference was attended by: Morita Kosuke, the experimental nuclear physicist who led the RIKEN team that synthesized nihonium (Group Director at the Research Group for Superheavy Element at the Nishina Center for Accelerator-Based Science), RIKEN President Matsumoto Hiroshi, Director of the RIKEN Nishina Center for Accelerator-Based Science En'yo Hideto, and Team Leader of the Superheavy Element Device Development Team Morimoto Kouji. Together, they proudly held up a board on which "Official Confirmation of The New Element 113. Nh. Nihonium." was written in large letters.

As Professor Morita was a little unwell, the press conference took place in Kyushu. (Morita is a native of north Kyushu and a professor at the Faculty of Science, Kyushu University) When he pointed at nihonium on a brand new periodic table, a mixture of relief and achievement could be clearly seen in the expression on his face. He had devoted some thirteen and a half years of work towards the goal achieved that day.

Incidentally, there was a special "discovery" that accompanied the synthesis of element atomic number 113: the discovery of a possibility that this element was created and then instantly disappeared during the explosion of a supernova star (there is thus a hope that making of this new element may hold the key to unravel the mystery of the creation of the universe).

Two Successive Syntheses

The periodic table is studied by all Japanese school children in their middle school science class as well as high school chemistry and physics classes. The first element in the periodic table (i.e. atomic number: 1) is the lightest, hydrogen. As the numbers get larger, the elements get heavier until they reach atomic number 92, uranium. The elements up to atomic number 92 exist in the natural world, but experimental nuclear physicists have continually worked to create heavier elements that do not exist naturally.

The device that the Morita research group used to create the new element is a part of RIKEN's Radioactive Isotope Beam Factory (RIBF), located on the first and basement floors of the Nishina Center for Accelerator-Based Science in Wako city, Saitama prefecture. The RIBF is made of several separate particle accelerators connected in sequence, and during the final stage nuclei are accelerated to 70% of the speed of light. This impressive Japanese-made experimental device can achieve the strongest beam power of ions in the world and its scale is quite incredible. The final stage accelerator weighs as much as two Tokyo Towers. The stage most used by Morita's team, however, was a 40-m linear accelerator located on the first floor of the building, known as RILAC. The beam emitted by the device is relatively slow at 10% of the speed of light. The reason is that in order to fuse together nuclei, they need to be "gently placed together."

The process that took place in the RILAC accelerator can be described as A + B = C. Nucleus A was accelerated towards the target nucleus B using RILAC. The two then fused together producing a new heavier particle C that does not exist in nature. Fusion occurs naturally in nuclear reactions, but it took one year of collision experiments to produce just a single new nucleus, an experimental process that required incredible patience.

This attempt to synthesize element 113 using this device began in September 2003. The experiments to create a new element proceeded smoothly, resulting in successful synthesis on July 23, 2004. This is how RIKEN reported on the event:

> *We have successfully discovered an element with an atomic number of 113 and heavier than any confirmed to date. This experimental result was achieved via 80 consecutive days of operation by a RIKEN linear particle accelerator with the world's strongest beam. The discovery was made by a research group led by Morita Kosuke, working at the Basic Accelerator Research Department of the Central Research Department (Department Director, Yano Yasushige).*
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> *Research to ascertain the existential limits of super-heavy elements and to search for new elements is taking place in other countries, such as Germany and Russia. By using a highly precise method to discover this one-hundred-and-thirteenth element RIKEN has taken the lead in the global race to*

synthesize super-heavy elements. […] If we can now bolster this data, such as by confirming reproducibility through multiple synthesis, in future we may earn the right to name this one-hundred-and-thirteenth element, thus leaving a permanent record of this historic event on the periodic table.

The news release concluded with a list of the teams that participated in the research: RIKEN, University of Tokyo, Saitama University, Niigata University, University of Tsukuba, the Japan Atomic Energy Research Institute, the Institute of Modern Physics, Chinese Academy of Sciences (in Lanzhou) and the Institute of High Energy Physics, Chinese Academy of Sciences. It also mentioned that the performance of the accelerator used to discover the new element had been improved in cooperation with the Center for Nuclear Study at the University of Tokyo.

Naming Rights Denied

Despite successful synthesis, experiments to confirm the results continued, and the second synthesis was achieved the following year on April 2, 2005, right after the opening of the Aichi Expo. Although both syntheses produced just a single nucleus each, two nuclei in two years was a remarkable result. When a new element is synthesized, the rule is that two international organizations, IUPAC (International Union of Pure and Applied Chemistry) and IUPAP (International Union of Pure and Applied Physics) recognize the discoverer and give the priority for the discovery of the new element, including the right to propose a name for it. In addition, it is the Joint Working Party (JWP) consisting of six individuals recommended by the two organizations that holds the right to confirm the priority for the discovery of the new element. Every few years, the JWP invites those who claim to have discovered new elements to put their names forward, in a process known as CALL. Morita's group entered the 2006 CALL, putting forward the two atomic number 113 nuclei successfully synthesized in 2004 and 2005.

At the same time, the German and the US-Russian teams put forward six sets of results covering atomic numbers 112 to 118 (with the exception of 117). Among them, only the German team that synthesized two nuclei of element 112 was granted the right to name the new element. Regrettably, the Japanese team's "element 113" was not recognized.

According to Morita: "In fact, we used the same method as the Germans to search for element 112 and successfully synthesized two nuclei in 2004. Since we succeeded in synthesizing the same number of nuclei as the German team which had already synthesized two nuclei, we thought we could share the naming rights so entered element 112 for that CALL as well… but regrettably, we were not granted the naming rights to it."

During the Cold War, there was a case in which the USSR and United States had both entered claims for the discovery of elements 104 and 105. Since both countries were granted naming rights, this example suggests that had Morita's team entered the CALL with element 112, their wish might have been granted.

But why didn't the Japanese gain the naming rights despite having successfully synthesized two nuclei of element 113 one after another? The answer is that the results of the synthesis experiments were deemed "insufficient."

Waiting for Alpha Decay

The Morita team aimed to create element 113 by bombarding (creating nuclear fusion) a nucleus of zinc (atomic number 30) with a nucleus of bismuth (number 83). It is a simple process of addition: 30 protons plus 83 protons equals 113 protons. Elements created by such artificial and forced fusion, however, do not stay that way for long. Less than a second after fusion, the nucleus decays stage by stage, changing into various different elements until it turns into stable elements.

Heavy nuclei mainly decay in two ways: alpha decay and spontaneous fission. The ratio of occurrence between these two decays depends on the type of nucleus, but both involve heavy nuclei changing into lighter nuclei.

Incidentally, during the process of alpha decay, a heavy nucleus gives off alpha particles (a helium-4 nucleus made up of two protons and two neutrons) and become a lighter nucleus. Meanwhile, in the process of spontaneous fission, a heavy nucleus splits into another heavy nuclei, then turns into lighter and more stable nuclei.

When the Morita team synthesized element 113, they discovered that it underwent four successive instances of alpha decay and turned into element 105 (dubnium). It was also known through experiments that the ratio of alpha decay and spontaneous fission by which dubnium decayed occurred at 67% and 33%, respectively. By accurately recording and confirming this rapid process of decays, they were able to demonstrate creation of a new element.

According to the Morita team, they were able to confirm the creation of a new element through alpha decay of bohrium during the 2004 and 2005 syntheses.

Says Morita: "Although we were able to synthesize for two successive years, there was only one previous example of bohrium decaying to dubnium, so that was not a sufficient proof. In addition, since the fifth dubnium decays were via spontaneous fission which occurs at the probability of the less probable 33%, there was a doubt that the data may have been incorrect. With only two phenomena observed, such cases are actually not unusual. One reason that they did not receive the naming rights despite successfully synthesizing two atoms of element 113 was that they did not achieve the dubnium alpha decay that had a 67% probability of occurrence.

Thus, from 2005, the team continued their experiments to bombard zinc nuclei with bismuth nuclei in order to capture more events of nuclear fusion and alpha decays. In fact, it was just a matter of keep on continuing their experiments and waiting for a "third time lucky" successful synthesis of a single atom.

Despite continuing with the collision experiments, and the successful syntheses that occurred in close succession in 2004 and 2005 however, for some reason the third synthesis completely failed to happen. Day after day, they bombarded zinc nuclei with bismuth nuclei; yet in 2012, even after many collisions, element 113 had still not appeared.

The Day of Destiny

While Morita anxiously waited for the desired results, he learned about an international conference that would take place in Vladivostok, Russia on October 1, 2012: its subject was exotic nuclei, i.e. unstable nuclei containing a very large number of neutrons. The main theme was "Creative Elements," and although Morita received an invitation to the conference, he declined to attend because, as he recalls, he felt shameful for "not having achieved any results for seven years."

In the meantime, for the first time in a while there was another CALL with a deadline of May 31. Although their third event had not yet appeared, Morita decided to re-enter the previous two results along with some new experimental data. The new data obtained by directly synthesizing a large number of bohrium showed that the bohrium created after the third decay of element 113 is the previously known nucleus. In addition, he included experimental results to confirm that dubnium created via alpha decay did undergo spontaneous fission and alpha decay with a probability of 33% and 67%, respectively. He hoped to earn the naming rights by providing additional experimental data to prove the accuracy of the decay process of element 113 already detected.

The day was Saturday August 18, 2012, two and a half months after the CALL. The temperature in Wako city in Saitama Prefecture was up to around 30°C, slightly more bearable than the preceding days when the temperature had reached over 35°C, but still a scorching day in a record-breaking hot summer.

On that day at RIKEN, a meeting of representatives from the C12 (a part of IUPAP) was being held. Over twenty representatives from the global nuclear research field had gathered with discussions starting at 9 am. As Morita was not one of the representatives, he had planned a day off. But since the members of the C12 had requested a tour of the RIKEN experimental facilities, Morita was waiting in his laboratory ready to be their guide.

Among the members of the C12 who had come to Japan was one of the JWP, the group tasked with assigning the naming rights for new elements. The individual was one of the six who had issued the CALL two and a half months before. For that reason, it was a great opportunity for Morita's team to properly demonstrate their experimental work.

At 1:30 pm, the chair of the C12, Sakai Hideyuki, who was also the head of the RIBF Research Division of the Nishina Center for Accelerator-Based Science, brought other members from various countries to the observation room located in the RILAC building which was used by Morita's team.

"Aaaaaa!"

Morita was struggling to say something he couldn't put into words.

"What are you so excited about?"

"It came!"

“Really? The naming right?”

“No, it…happened!”

The “it” in question was an event, namely a confirmation that a new element has been synthesized. Sakai repeatedly tried to persuade his colleague to calm down, but Morita could not contain his excitement.

“The fourth alpha decays!”

The alpha decay that they had waited seven years for had just been confirmed. Among the international members who observed Morita’s excitement was a personal friend, a researcher from Finland. When he learned that Morita had successfully confirmed the synthesis of element 113, he offered his heartfelt congratulations.

But Was It An Accident?

It certainly was a strange twist of fate that one of the key people who decides on the priority in granting the new naming rights happened to step foot in the Morita team laboratory just after the researchers confirmed a result they had waited for some seven years.

Following is the sequence of events that occurred on that day when the synthesis of element 113 was confirmed.

The following day (Sunday, August 19) at RIKEN, a power cut had been planned as part of the routine inspection of the facility. Sumita Takayuki, a member of the Morita team and a graduate student at the Tokyo University of Science, was at the lab preparing for the power cut. At the same time, he was working on a week’s worth of unanalyzed experimental data. As he continued with the analysis, he came across some data from August 12, the day of the closing ceremony of the London Olympics. Among it was a section that seemed like an alpha decay resulting from the synthesis of element 113. Sumita called Morita’s extension number.

“I see what looks like traces of element 113,” he told Morita.

No doubt it was the third atom of element 113 they had spent seven years waiting for. At the time when Morita greeted the international representatives, only four stages of alpha decay had appeared in the analysis, but by the time the tour had finished, the analysis showed that there were two other instances in the observation data. Dubnium had exhibited alpha decay! They confirmed that alpha decay turned dubnium into element 103 (lawrencium) then settled as the stable element 101 (mendelevium). It was a complete success. They immediately relayed the news to Yano Yasushige and other prominent members of the laboratory.

There existed already a contact network in case of such an event. The first person to receive the news from Morita was Onishi Yukari of the Planning Office of the Nishina Center for Accelerator-Based Science, who was responsible for PR and international conferences and happened to be in the vicinity. Onishi followed the chain of communication and used her mobile phone to first call the Center's director, En'yo Hideto, who was then on his way back home.

"Please listen calmly," she said. "Morita has something important to tell you."

En'yo's immediate thought was "An accident? Someone got injured?" but when he heard that element 113 had been observed again, he rushed back to the laboratory.

Says Morita: "During 2004 and 2005, it took around 100 consecutive days of collision experiments for each of the two nuclei. That's why I assumed it would take about another 100 days for the third nucleus to be synthesized. But even after 200 days, then 300 days, it did not happen. It took seven years and a total of 360 days of collision experiments for element 113 to finally appear. What's more, we observed dubnium's alpha decay. I almost went crazy with excitement."

That evening, the Nishina Center's members gathered in the observation room for a celebration which lasted endlessly.

"We drank ourselves silly, so I don't remember what time we finished," says Morita.

Towards the Synthesis of Extreme Elements

More than three years and four months had passed since the successful synthesis. New Year's Eve was approaching and Morita was wondering what on earth was going on, and whether yet another year would go by without a notification of the right to name the element being granted.

But in the early morning of December 31, 2015 the author suddenly heard the huge news that the naming rights for element 113 had been granted. Immediately, I wrote an article about the big announcement and sent it to the editorial department of *Nikkei Business ONLINE*, returned the revised version as I listened to the temple bells being rung on New Year's Eve, then after midnight, it was published as my first regular column of the new year. When I was a young reporter, I had written articles on short notice about major disasters or serious accidents but I have never written one with such a feeling of urgency and excitement. (I am deeply grateful to the editorial staff who dealt with the report on New Year's Eve.)

Now, my interest turned to the name and symbol for the element that Japan would propose. There were rumors of names such as japonium and rikenium, but after a month, then two months, still nothing happened. Half a year later on June 8, 2016, I was still wondering what was going on when I learned from RIKEN that at 10:30 pm that day, Japan's suggestions for the name and symbol would be announced on the IUPAC's (International Union of Pure and Applied Chemistry) website. I logged on to the IUPAC website and waited for the page to be updated.

Sometime after 10:30 pm, along with the names for elements 115, 117 and 118, the name and symbol for element 113 appeared: nihonium and Nh. It was explained in the website how the name came from the Japanese word for Japan, *nihon*: the land of the rising sun. It also expressed hope that the naming would help recover some of the pride and confidence in the country's science that had been lost during the Fukushima nuclear disaster.

I sent a message of congratulations to Morita right away and received an immediate reply:

Dear Yamane,

The way in which your articles have expressed the enthusiasm that we share has made me very happy. Thank you.

I am extremely happy, and also relieved, that I can finally refer to "nihonium," the carefully considered element name that we proposed to IUPAC in March. As we engage naturally and with dedication in our research into basic science, it is a great pleasure to occasionally produce results in a form that is easy for the general public to understand.

I will be absolutely delighted if activities such as these can help us gain the trust of the Japanese public.

Although the name "nihonium" had already been made public, there was a delay of six months due to a public review of the name and symbol before the final confirmation. Then finally, on November 30, 2016, the addition of element 113 to the periodic table was announced.

That so much time and painstaking paperwork had been required was a testament to the periodic table's role as an absolutely fundamental tool of science.

The element 113 project was completed on October 1, 2012, but when I went to visit Morita soon afterwards, experiments to synthesize (i.e. discover) element 119 had already begun. The team was already moving forward towards further research topics and challenges.

The elements 101 to 103 are known as "heavy elements," and those with atomic numbers 104 and higher are called "superheavy elements." As the atomic numbers get higher, the elements get heavier, with the theoretical upper limit being element 172 or 173. Morita hopes that the next generation of scientists will work on these "extreme elements."

Since element 113 turns into a different substance in half of one thousandth of a second, it is not useful to society. It cannot be sold to make a profit. Yet, Morita's team and RIKEN have achieved for Japan something that is not measured by money, but rather by merit and glory that will go down in the history of science forever. There is no doubt that many of the younger generation who learn about this noble work will be excited and choose the path of science, thus becoming a new source of strength and prosperity for Japan in the future. This is indeed the path of science that RIKEN has pioneered in the past 100 years.

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*Related information (Japanese only): http://bookclub.kodansha.co.jp/product?isbn=9784065020098

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