The hunt is on

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The Japanese element hunters are trying to extend the periodic table

The emperor of Japan wants a new element. In Wako, on the outskirts of Tokyo, a team of scientists at Riken's Nishina Center for Accelerator-Based Science are searching for one. It's a race between Riken and their friendly rivals at the Joint Institute for Nuclear Research in Dubna, Russia, to discover element 119 – and the Japanese have a head start. The winner will need skill, some of the most powerful research machines ever created and good fortune. 'We have the best beam in the world,' says Hideto En'yo, the centre's director. 'But I don't know if we have the best luck in the world.'

In 2016, a Riken team led by Kosuke Morita was officially recognised as the discoverers of element 113, pipping an American–Russian team under Yuri Oganessian (the only living scientist to have an element named after him). It had taken the team nine years of searching, running their atom-smashing accelerator 24 hours a day, with 50 people working in shifts: watching, waiting and hoping. Starting in 2003, they first saw a glimpse of a new element in 2004. Another sighting came in 2005. But it wasn't until 2012 that they finally saw a third atom, confirming their discovery. When asked to come up with a name, there was only one choice: nihonium, after the Japanese word *nihon* meaning land of the rising sun.

Since then, chemistry fever has gripped the nation. Every school in Japan knows about the new element – when En'yo phoned his daughter to tell her they'd discovered it, she'd already heard about the search in her high school class. Wako has built a giant periodic table walking trail, with each element engraved in bronze flagstones that lead from the train station to Riken's doorstep. The element creators have been turned into manga comic characters, and the team even has its own brand of sake (rice wine) on sale across Japan that uses yeast irradiated in the centre's ion beams.

En'yo says the cost to search for 119 will be around $1 million a year (£740,000). The hunt for element 113 was almost abandoned because of lack of resources, but this time Japan's emperor is bankrolling Riken's efforts to extend the periodic table to its eighth row. In December 2017, the team started up the first of two experiments that will look for the element; the second will come online in 2019 after a $146 million (£108 million) upgrade, just as the Russians begin their own experiments. 'Sometime in 2019, we'll go in parallel,' says En'yo. 'And we'll keep running the experiment until we make the discovery – or someone else does!'

Having a smashing time

The elements beyond plutonium do not exist on Earth; they have to be made in a laboratory. The theory behind making these superheavy elements is simple – two atoms are smashed together to make a bigger one. To make the next element, all the Riken team needs to do is combine two elements with proton numbers that add up to 119.

In practice, it's not so easy. As both nuclei have a positive charge from their protons, electrostatic repulsion means the two are likely to simply bounce off each other (like trying to push two magnets together). Instead, you have to smash them in a high energy collision, hoping that the two nuclei fuse together. The easiest way is to set up a target containing one of the elements, then hit it with an intense ion beam – a superhot plasma – of the other.

This involves using a particle accelerator. These giant devices, worth millions of pounds, use magnets to fire a steady beam of ions toward the target at about 10% the speed of light. The Riken team has both a linear accelerator – effectively a 100-metre magnetic gun – and a cyclotron, which spins the ions in a circular orbit, getting faster and faster with each pass. Both pepper the target with about 1×10^{13} ions a second. Only a direct hit will do (otherwise the two nuclei bounce off each other) and, even with constant bombardment, a direct hit is rare. As the discoverer of the nucleus, Ernest Rutherford, once said: 'it's like trying to shoot a gnat in the Albert Hall at night, using 10 million rounds of ammunition on the off chance of getting it'.

Once a nucleus is hit, you have another problem: the energy required to get past the electrostatic repulsion is often too much for it to handle. This causes the nucleus to shake itself apart in a process called nuclear fission. Not enough energy and your ion beam bounces off; too much and your target breaks up.

Even if the two nuclei do fuse together, you then have to detect it among all the noise of everything else going on. Superheavy elements don't last long – the longest known half-life of a nihonium isotope is eight seconds. Element 119 will be far shorter: it'll decay in literally the blink of an eye.

Heating things up

The Riken team is also performing experiments nobody knows will work. Nihonium was discovered using cold fusion – a method that had already allowed a German team based in Darmstadt to discover elements 108–112. Cold fusion involves firing a beam of a lighter element at a heavier element target (the Japanese used zinc at bismuth). These beams have relatively low excitation energies, meaning that fission isn't a problem; instead, it is rare for them to overcome the electrostatic repulsion. While cold fusion works, it doesn't produce a lot of new atoms – unless you run the experiment for hundreds of years, the chances of making even an atom of anything past nihonium are virtually non-existent.

'For the new element, using cold fusion is hopeless,' explains Kouji Morimoto, a member of Riken's accelerator team. 'So we decided to use hot fusion instead.'

This is the method the American–Russian team used to discover elements 114–118. In hot fusion, there is a larger mass difference between the elements used in the beam and as the target. The atoms in the lighter beam are also rich in neutrons; the newly fused nucleus discards these extra neutrons – lowering its energy levels to avoid fission. All the previous elements created using this technique used a beam of calcium-48, a naturally occurring isotope with eight bonus neutrons. Unfortunately, calcium can't be used to discover anything past element 118. The next target with the right number of protons is einsteinium, a rare and highly radioactive element first discovered in the aftermath of an atomic bomb. There isn't enough einsteinium in the world to produce a single target, and it's too expensive to make it just for the experiment.

Instead, the Russians plan to use a titanium beam to bombard berkelium and the Japanese are using a vanadium beam into curium. Nobody knows for certain which approach is best, but both teams need to source their targets from the same place.

Target practice

Curium and berkelium are highly radioactive elements. The only non-military nuclear reactor able to create them in large enough amounts is at Oak Ridge National Laboratory in Tennessee, US.

Oak Ridge is the birthplace of nuclear power. It was here, in 1943, that the US military built the first permanent nuclear reactor to make plutonium for the atomic bomb. Now one of the largest research facilities in the world, Oak Ridge still leads the world in making elements – it's why element 117 was named Tennessine.

Making the targets for 119 starts at the High Flux Isotope Reactor (HFIR), deep in the woods on the edge of the Smoky Mountains. Inside, target rods of uranium are bombarded with neutrons. As neutrons aren't affected by electrostatic repulsion, they are captured by the nucleus, which then undergoes beta decay – turning a neutron turning into a proton. By controlling the length of time in the reactor, you can control the element you make.

Once the required target has been created, it is moved up through the hot labs – a radioactive containment facility where chemists puppeteer the samples with giant claws, safe behind 54-inch concrete and three panes of leaded glass. Acids are used to separate the elements the reactor has produced (nothing goes to waste – the separated elements are all collected and extracted).

Curium, for the Japanese team, hisses with alpha radiation. When the target was made, it never left containment at Oak Ridge: the sample was too dangerous. From there, it was shipped it to Japan by passenger airline. In the past, pilots have refused to handle such dangerous cargo; this time the curium arrived safely at Riken.

Using curium puts the new experiment in a whole new category of difficulty to the one Riken used to discover nihonium. Bombarding targets with an ion beam damages them over time; usually a series of targets can be arranged on a disk and rotated to make them last. The Riken team won't have enough curium to do that. And, unlike bismuth, it's radioactive, requiring more safety precautions. 'In the case of the bismuth targets, we changed them every week, they're cheap [and safe],' says Morimoto. 'This new target is expensive. We have to use the same target for a year, maybe even three years. We're going to have to use it carefully.'

What's the point?

The curium target has now been loaded at Riken. The experimental beams have been tested on other targets, and are now firing at the curium in the hope of finding something. Up in the control room – a mess of wires and readouts, the odd cuddly toy propped up on the desk for luck – the element hunters are waiting for their first bite. Although this isn't the only experiment the Nishina Center does, it's the prize: and all of them are ready, potentially, to give the next decade of their lives to the project. Why?

'It's a good question,' says Hiromitsu Haba, one of the team's chemists. '[Superheavy elements] have a short half-life and no practical application. But the elements are very important for the universe, for the body, for everything! If we can understand such elemental particles, we can come up with good theories [about how things work]. Currently, we know about 3000 isotopes of elements. But theoretically there are 10,000 isotopes. We know only a third of our world.' The team's greatest hope is that they land on the so-called island of stability – the right combination of protons and neutrons that mean the nucleus is stable, with half-lives of thousands of years. Superheavy elements on or near to this 'island' won't be solely confined to the laboratory any more.

Even without the island, there is hope for carrying out chemistry on superheavy elements. The Riken team has already started to perform some basic tests on another man-made element, seaborgium, running gas-phase experiments in the few seconds they have before the element vanishes. 'If the half-life is longer than one second, we can do chemistry,' Morimoto says. 'For example, we produced seaborgium isotopes, caught them and added carbon monoxide gas, so we confirmed it forms a hexacarbonyl.'

If that sounds relatively simple, keep in mind the experiment was performed using only 18 atoms. It's an important step in working out how the superheavy elements behave. At this end of the periodic table, the greater mass of the nucleus means quantum mechanics have an even greater impact, and elements may not follow the trends of their group (in the same way that mercury is a liquid at room temperature). Even the most basic experiments provide useful clues about the fringes of the periodic table.

And we may not need to wait long for more elements to add. En'yo predicts one of the two teams will find element 119 – and maybe element 120 – within the next five years, stretching our knowledge of the atomic world a little further (although it may take up to a decade after that for the discovery to be officially recognised). For now, all the emperor of Japan can do is wait with the rest of the world.

And if the Japanese are successful, what would they like to call the new element? The Riken team told me a few of their ideas, but I don't want to spoil the surprise.

Kit Chapman