SUPERHEAVY ELEMENTS

Scientists search for an isle of stability in a sea of instability

BY KENDRICK FRAZIER

The quest for superheavy elements, whatever the eventual outcome, will in some future time be a rich subject for historians and sociologists of science. The search for elements considerably heavier than those now known to exist is high-stakes science. The potential gains, both in reputation to the first acknowledged discoverer (it could be Nobel-Prize-magnitude subject matter) and in the advancement of understanding of possibly new physical phenomena, are enormous.

Already the path is littered with the debris of claimed evidence that fell by the wayside under the intense scientific scrutiny that confronts all important claims. Other pieces of evidence still stand, awaiting much-needed support and bolstering. Some claims have been retracted almost as soon as they were advanced. Others have been left to wither on their own. And, in one remarkable recent case, the lead author of a widely noted report of evidence for superheavy elements has, upon further evidence, retracted his claim only to have several of his co-authors decide to stick with it.

Laboratories throughout the world push forward the search. Accelerators gear up to try to create superheavy elements. Mica from Madagascar, meteorite samples from Mexico, even the moon, are examined for evidence of superheavy elements in nature.

For all the frenzied activity, none of the attempts have resulted in any conclusive evidence for the existence of superheavy elements. That fact is acknowledged by all. O. Lewin Keller Jr. of Oak Ridge National Laboratory points out that laboratories at various sites, including Dubna (USSR), Stanford (USA) and Strasbourg (France), have recently obtained results "which are encouraging," but so far nothing tried has produced "a generally accepted superheavy element discovery."

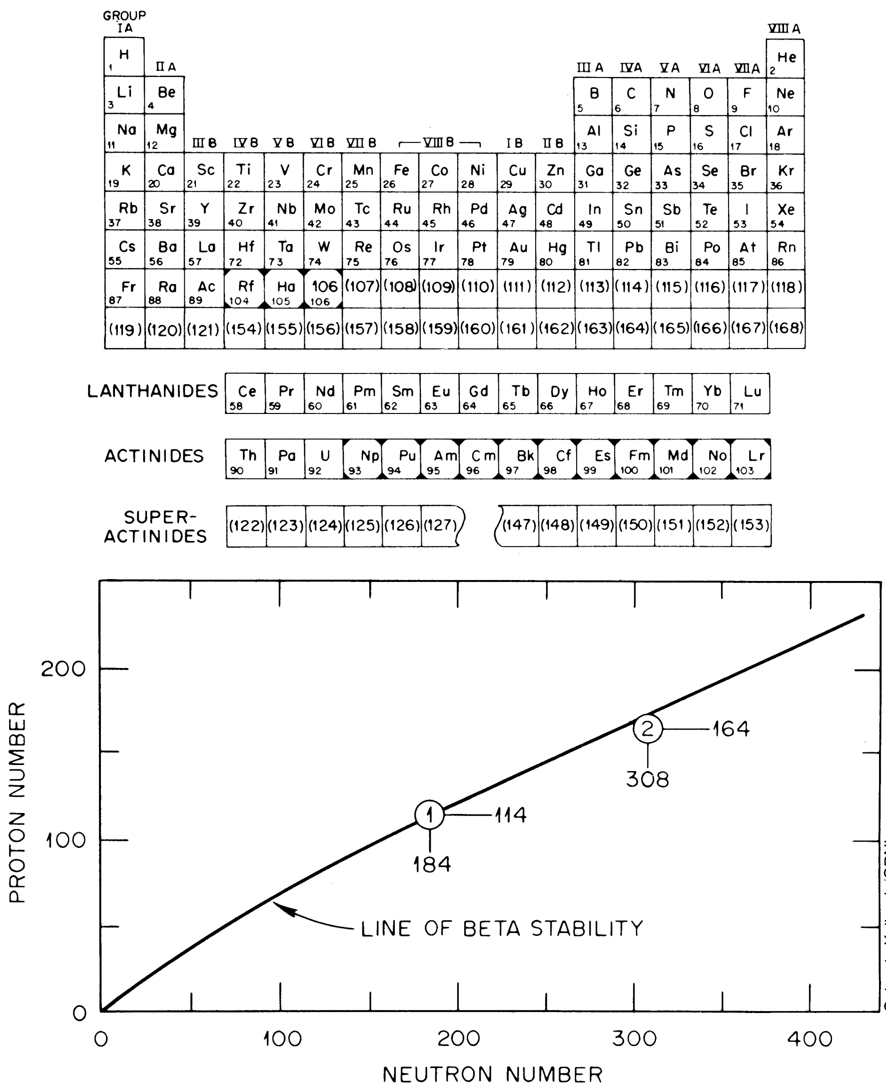
Despite the lack of evidence, few workers seem discouraged. Many are even optimistic. "The possibilities still appear strong," says Keller, director of the chemistry division at Oak Ridge, who gave the opening overview presentation at the International Symposium on Superheavy Elements at Texas Tech University in Lubbock, March 9 to 11. The meeting attracted scientists from 15 countries to compare and debate recent results. Of the major research groups involved in the quest for superheavy elements, only the Soviets were not represented at the meeting.

The current wave of international interest in superheavy elements began in the late 1960s, after predictions were made that unusual stability of the nucleus would be found at about hypothetical element 114. (The heaviest element so far known conclusively is 106.) Just as some chemical elements — the noble gases — have unusual chemical stability because their electron shells are closed or complete, the nuclei of some atoms have extra stability due to closed shells of protons or neutrons. Calculations suggested the existence of closed shells at proton number 114 and neutron number 184, and also at proton number 164 and neutron number 308. This suggested extra stability for a range of nuclei in the neighborhood of these so-called "magic numbers."

Thus, element 114, having 114 protons and 184 neutrons (and therefore atomic weight 298), would be especially resistant to radioactive decay. It and nearby elements such as 112 and 116 might, therefore, if ever produced, last long enough to exist in nature. The search was on for elements in this so-called friendly "island of stability" surrounded by the hostile "sea of instability." The supposed find would be the "superheavy" elements.

It is difficult even for scientists to resist the geographical metaphor. "For the past 10 years we have struggled to reach this island," say Curtis E. Bemis Jr. of Oak Ridge and J. Rayford Nix of the Los Alamos Scientific Laboratory. "Countless explorers have returned without even a glimpse of the island. Some, perhaps ill-prepared to make the journey, have shouted 'Land ho!' only to have it slowly fade before their eyes....

"Why are we caught up in this frantic search? Partly because of the same in-



Futuristic periodic table (top). Elements 112 and 114 would fall below mercury and lead. Elements 122 to 153 would form a second row of actinides called superactinides. Island of stability at 114 protons and 184 neutrons, plus second hypothesized island at 164 protons and 308 neutrons.

stinct to explore the unknown that drove Columbus to the New World, Hillary to the top of Mt. Everest, and Armstrong and Aldrin to the moon. ... Of course, Hillary knew that Mt. Everest had a top, and Armstrong and Aldrin knew that the moon was accessible. We do not even know that superheavy elements can even exist, apart from the questions of how to produce them in the laboratory or where and how to look for them in nature."

The search is on the forefront of science. It has the glamour that accompanies a quest for the total unknown. In its strong reliance upon theoretical predictions the quest for superheavy elements, Bemis and Nix note, may be likened to the search for magnetic monopoles, quarks, anti-particles, black holes and superdense nuclear matter. Unknowns abound. In the words of Subramanian Raman of Oak Ridge, "It is on the border between science and speculation."

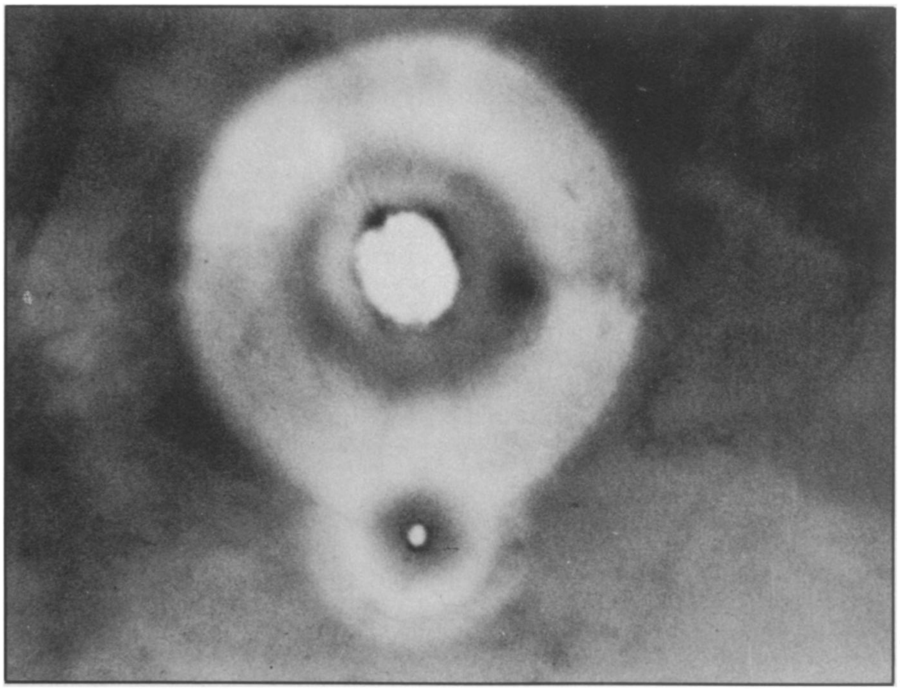
The scientific fruits of a discovery of superheavy elements would go far beyond a mere extension of the periodic table. It would help decide between many competing nuclear and atomic theories or perhaps suggest new ones. And, many proponents suggest, the discovery could serendipitously reveal entirely new physical phenomena.

So far, all attempts to produce superheavy elements in accelerators have failed. (It is this fact that leads one scientist to note that accelerator people are generally more pessimistic about the eventual success of discovery of superheavy elements than are those who are looking for them in nature.)

A systematic search for superheavy elements based on their possible synthesis by the bombardment of curium 248 with calcium 48 ions has been underway for some months at the Superhilac accelerator at Lawrence Berkeley Laboratory. (Calcium 48 ions became available for the first time in 1976.) That particular reaction was chosen as the optimum for producing nuclides near the center of the island of stability. Both projectile and target are rich in neutrons, a necessary condition. The reaction of xenon 136 with uranium 238 has also been tried. So have dozens of other combinations of target and projectile nuclides. To date, E. K. Hulet of Lawrence Livermore Laboratory and J. M. Nitschke of LBL reported at the Lubbock symposium, all have been unsuccessful.

Still, however, a large region of shorter half-lives and smaller formation cross-sections remains to be explored in the Superhilac work, notably half-lives less than a tenth of a second and cross-sections smaller than 10^{-34} square centimeters.

R. J. Otto of Glenn Seaborg's group at Berkeley notes that it is always possible that superheavy elements are being formed but not being detected. Their half-lives could be too short to be detected or



A typical giant halo with a normal halo on its edge.

their fission properties (by which they are also detected) could be so similar to those of the actinide elements (numbers 90 to 103) that they could not be distinguished.

A new kind of detector, called SASSY, for small angle separation system, will be put into operation on the Superhilac by summer. The results of the bombardment are put through a gas-filled magnetic field.

"If a superheavy particle goes through there we will be able to detect it regardless of decay time," says Albert Ghiorso of LBL. "If that fails my faith will go to zero."

Of course Ghiorso, whose name is attached to the discovery of many of the transuranic elements, has never been known for optimism concerning superheavy elements. Four years ago he bet Seaborg, another prolific element discoverer, $100 that no superheavy elements will be found. He entered into the wager even though, as he notes with a smile, "It's a bet I can't win," since no time limit was set. "I can only lose."

One of the best hopes for producing superheavy elements is considered to be the new UNILAC accelerator in Darmstadt, West Germany. It is the only accelerator in the world using a uranium beam. Studies are underway, but so far attempts to produce superheavy elements using uranium 238 for both projectile and target have been unsuccessful.

The UNILAC has also been used to try to confirm an observation by the Dubna group in the Soviet Union tentatively assigned by the Soviets to superheavy elements. The reaction involved xenon 136 and uranium 238. The UNILAC results were negative.

Not all word from the UNILAC work is pessimistic, however. The uranium-uranium collisions showed increased ability to form actinide nuclei up to fermium (element 100). According to Günter Herrmann of the University of Mainz, who reported the UNILAC results, "This may be taken as evidence that production of superheavy elements in reactions between very heavy nuclei is within reach."

The search for superheavy elements in nature has generated considerably more excitement than the attempts to produce them in accelerators. Predictions of possibly long half-lives (although the Lubbock meeting reveals there are still tremendous uncertainties on this question) on the order of 100 million or a few billion years led to hopes that superheavy elements might be found to exist naturally somewhere.

The latest wave of ferment began in 1976. Researchers at Oak Ridge, Florida State University and University of California at Davis reported "evidence for primordial superheavy elements" in microscopic inclusions of monazite found within giant haloes on mica from Madagascar (SN: 6/26/76, p. 404). This claim soon ran into difficulties when it became known that the line in the X-ray spectra of the inclusion, interpreted by the group as due to element 126, could have been produced by a gamma ray emitted by reaction between the protons used in the detection test and nuclei of cerium atoms in the inclusions.

So the lead author, Robert V. Gentry of Oak Ridge, and four Oak Ridge colleagues not associated with the previous work, analyzed the inclusions using an entirely different technique at the Stanford Linear Accelerator Center. Synchroton radiation, which unlike protons does not excite the nucleus (thus avoiding the cerium-gamma-ray-problem) and also can be tuned to distinguish between adjacent competing spectra lines, was used to irradiate the inclusions. Their conclusion (SN: 2/5/77, p. 85; 2/26/77, p. 131) was that no superheavy elements in the range from elements 105 to 129 were present at levels of concentrations at least a factor of 10 less than in the originally reported experiment.

Just recently the synchroton radiation analyses have been repeated at Stanford in an improved experiment said by the group to be 55 times more sensitive than the originally reported experiment. They report that the results show "conclusively that at concentration levels of about 500 million atoms per inclusion superheavy elements are not present" in giant halo inclusion 19D (one of the original ones used as evidence of superheavy elements) or in numerous other giant-halo inclusions studied. "We conclude that the previously reported evidence for superheavy elements is invalid." The report, by C. J. Sparks, S. Raman, E. Ricci, Gentry and M. O. Krause, is published in the Feb. 20 Physical Review Letters.

At the Lubbock symposium, Gentry made clear that while in 1976 he believed the evidence warranted the deduction that the inclusions contained element 126, now he does not. "At present, I do not have evidence for superheavy elements in giant halo inclusions.... As the evidence stands today, I will accept the view that the synchroton radiation experiments did not confirm element 126."

Gentry emphasizes that in making that statement he speaks only for himself: "I don't speak for anyone else and they don't speak for me."

The reason he says that, is that some other co-authors of the original report have not given up the claim. Thomas A. Cahill of the University of California at Davis, for instance, vigorously defends the group's original report and strongly disagrees with Gentry's about-face. "The evidence for 126 in giant haloes has not gone away," he told Science News. "It's even stronger." He disputes the statement by the Oak Ridge group that their Stanford synchroton analyses are more sensitive than the original experiments, contending that the protons used to induce emissions in the original work may have been reaching only atoms in the upper layers of the inclusions. This would mean the emissions recorded came from a smaller volume of matter than supposed. He also points out that members of the Davis and Florida State groups are specialists in the identification of X-ray spectra. "The lines are there," says Cahill. "Something is there."

Gentry acknowledges that there are some things about the original experiment that even today he does not understand. "But," he told Science News, "I have to face it. In my opinion the Stanford work is of a sensitivity that it should see it [any evidence of superheavy elements]."

But if the giant haloes surrounding the monazite inclusions were not caused by decay of superheavy elements, what did cause their extra size? (Normal-size haloes are well understood to have been etched by alpha particle decay from specks of uranium and thorium in the inclusions.) One hypothesis is that radioactive gases diffused outward through cracks in the mica, thus artificially extending the size of radiation-damaged area. At the Lubbock meeting Gentry hypothesized an alternate explanation — that groundwater fluids where the mica deposits lay may have infiltrated the mica and chemically reacted with the radiation-damaged regions in such a way as to allow the regions (the haloes) to expand. Neither explanation requires the existence of superheavy elements.

Whatever the eventual outcome of the superheavy elements race, the case of the giant halo inclusions will have its own fascinating little niche in the history of science. And Gentry, like so many other scientists who have sought them but ended up reporting negative evidence, says he nevertheless remains "optimistic about eventually finding superheavy elements."

Not all the reputed evidence for superheavy elements in nature comes from giant halo inclusions.

Georgi N. Flerov and colleagues at the Dubna research center in the Soviet Union have recently claimed evidence of superheavy elements from three samples of the Allende meteorite and from samples of hot brine water from an underground spring in the Soviet Union. Here the issue is reliability of the data. Some scientists simply don't believe it. Flerov has made many claims of element discoveries in the past that were later proved wrong. His first claim of a superheavy element discovery dates back to 1969, but was subsequently shown to have a prosaic explanation. "He's a capable guy, quite capable of making such a discovery," says one American scientist of Flerov. "The problem is he's not a *reliable*, capable guy." Unfortunately, Flerov could not come to the Lubbock meeting to describe and defend his work (he sent his greetings and regrets).

Flerov's Allende claim is based on only one unexplained fission count per month, and so the statistics of the data are not good. It nevertheless remains puzzling. The hot springs data can be explained, George Flynn of Washington University in St. Louis told the Lubbock meeting, by the presence in the water of isotopes of californium, curium and plutonium from past hydrogen bomb tests.

Edward Anders's research group at the University of Chicago two years ago reported anomalous enrichments of heavy xenon isotopes in the Allende meteorite that they said could be fission products of a superheavy element. Since then, recalculations have shown that fission of known elements could have produced the xenon. Two negative experiments reported at Lubbock by Robert M. Walker of Washington University do not rule out superheavy elements in Allende, says Walker, but do place severe constraints on their possible nature.

D.R. Walz and J. Maly of the Stanford Linear Accelerator Center reported at Lubbock their observation of 14 fission tracks longer than tracks produced by uranium fission. The tracks were observed on mylar foils left underground for three years (to avoid cosmic rays) while exposed to radiogenic lead. Walz and Maly contend that the long tracks "are best explained as resulting from the spontaneous fission of natural, superheavy elements in the proposed element 114 stability range." These data, though interesting, are not in themselves very persuasive, according to several observers.

One exotic and controversial event, once claimed by its observers as evidence of a magnetic monopole, has now been suggested by them as possibly being due to a superheavy element. W.Z. Osborne of the University of Houston was a member of the group that in 1975 interpreted a unique cosmic ray track through a balloon-borne array of Lexan and nuclear emulsion as the path of a magnetic monopole. The group now consider that explanation untenable, says Osborne. But he says an ultrarelativistic superheavy element can also account for the data.

And S. Keith Runcorn of the University of Newcastle upon Tyne recounted at Lubbock his recently published (Science, Feb. 17) argument that superheavy elements may have been present in the early moon. Superheavy elements, he contends, could have been the powerful heat source necessary to melt the early moon to its center. A once-melted core seems required in his view to produce a core dynamo that would in turn generate the early lunar magnetic field that he believes is implied by magnetized ancient lunar samples from Apollo missions.

It is evident that there is no shortage of tantalizing bits of evidence and mind-stretching speculations concerning the possible existence of superheavy elements. The abundance of claims of evidence put forth is not surprising, even when many seem destined for downfall. With the stakes as high as they are for any eventual confirmed discovery, a potential discoverer has much to gain by getting his claim on record early. And, because there is considerable optimism that superheavy elements will eventually be found, "Those who have made claims," says one scientist, "do not retract them. They have nothing to gain by retracting."

The need now is for conclusive experiments, especially by those who think they see signs of superheavy elements in nature. "It is their responsibility to come up with more definitive experiments," said conference chairman M.A.K. Lodhi at the conclusion of the Lubbock symposium. "Anomalies are there, but that doesn't mean they are superheavy elements. We need positive evidence, and that we don't yet have." □