Desert chemistry. U.N. inspectors in early 1998 prepare to destroy Iraqi missiles that reportedly had been filled with sarin.

security, who tried to persuade him to recant. Shahristani refused. That rejection earned him 10 years in solitary confinement, in a room with no windows, no reading or writing material, and a single 15-minute chaperoned visit per month from his wife. He did not want to give the regime the pleasure of seeing him go crazy. "It sounds silly now, but I tried to make puzzles and then solve the puzzles that I'd just made myself," Shahristani says. A devout Muslim, he prayed and recited sections of the Koran from memory to have "conversations."

Shahristani eventually was moved out of solitary confinement, and during the Gulf War in 1991, he seized an opportunity for escape: During a nighttime bombing raid, he stole a car and uniform of the prison's chief security officer and simply drove out past the guards. He and his family, along with a million other Iraqis, fled over the border that March into Iran.

Iconoclastic views. Shahristani's refugee experience has shaped his activities ever since. In 1995 he set up the Iraqi Refugee Aid Council, which has helped tens of thousands of Iraqis in camps in Iran by setting up clinics, schools, and self-help programs. Two years ago he moved from Iran to London, the center of Iraqi political opposition and a focal point for the United Kingdom's estimated 250,000 ethnic Iraqis, where he has continued his work with refugees. "Unlike others who defected, he risked his life to continue to try and do something, to stay as close as he could to Iraq, to help the refugees, to document the abuses," says Shelley Saywell, who in 1995 directed a Canadian documentary of Shahristani's life.

What also sets Shahristani apart are his views on Iraq's weapons programs. He downplays concerns that Iraq is on the verge of acquiring a nuclear bomb. "Iraq basically has the know-how to assemble a crude nuclear device, but it lacks the fissile material," he says, basing that conclusion on information from resistance cells and well-placed scientists in Iraq as well as his contacts with recent defectors. He discounts the recent revelation by the U.K. government that Iraq has been trying to purchase uranium ore from Africa, claiming that the regime lacks centrifuges and other equipment to enrich it.

Others are more cautious. Albright, a longtime Iraq analyst, says Shahristani may be underestimating his former employer. "You have to worry that Iraq is reconstituting its uranium-enrichment program or even dabbling in plutonium," he says. "It's very hard to detect these activities."

But Shahristani is far from dismissive of Hussein's biological and chemical ambitions. Concerns are running high about possible covert work on botulinum, anthrax, gas gangrene, and aflatoxin (*Science*, 16 August, p. 1110), and Shahristani says that his own sources suggest such concerns are justified. He has also raised disturbing new questions about Iraq's chemical weapons program. U.N. inspectors know that Iraq started working on mustard gas in 1982, followed by sarin and tabun. Shahristani backs claims from defectors that prisoners were used as guinea pigs. "Thousands of people were taken from prisons for experiments," he alleges. He also asserts that much of the R&D on chemical and biological weapons has ended: Most scientists in these programs "were sent back to the universities. The regime has decided it has enough know-how to use its inner core of security officers to do the production work."

His most explosive allegation, however, is that the Iraqi military has placed tons of chemical weapons, including the devastating nerve gas VX, in Shiite villages in the southern half of the country and intends to detonate the stocks in the event of a U.S.-led invasion. Based on its suspected covert precursor stocks and available equipment, Iraq has the capability of producing "tens of tons" of VX, notes a former U.N. chemical weapons inspector.

However, no experts have corroborated this scenario, and a few are dubious. The booby-trap scenario is "unlikely," argues Kelly Motz, an analyst on Iraq at the Wisconsin Project on Nuclear Arms Control in Washington, D.C. It "would undermine [Hussein] in the eyes of Arabs and help justify the U.S. position." Shahristani strongly disagrees, noting that Hussein has already used poison gas on his citizens, against Iraqi Kurds in the late 1980s. Sensing a coming confrontation, Shahristani fears "a potentially very serious human catastrophe" facing the Iraqi people—a suffering that he knows all too well.

–ANDREW WATSON

Andrew Watson is a writer in Norwich, U.K. With reporting by Richard Stone.

NUCLEAR PHYSICS

Accelerator Aims to Find The Source of All Elements

Nuclear physicists hope that an expensive atom smasher will reveal the secrets of stellar alchemy, but first they have to secure funding

We are all made of starstuff. The big bang created hydrogen, helium, and a little bit of lithium and other light atoms. But everything else—the carbon, oxygen, and other elements that make up animals, plants, and Earth itself—was made by stars. The problem is that physicists aren't quite sure how stars did it.

The answer, they hope, will be revealed by an $840 million machine called the Rare Isotope Accelerator. RIA will smash stable atoms into fragments, producing rare, unstable nuclei that play a brief but crucial role in the creation of heavy elements. By studying these unstable nuclei—analyzing their half-lives, their ability to capture neutrons, and other properties—scientists believe they will finally be able to figure out where all the heavy elements are born. "RIA's the machine that will nail the entire issue," says Claus-Konrad Gelbke, a nuclear physicist at Michigan State University in East Lansing.

If RIA is a nail, then the Department of Energy (DOE) seems to be a reluctant hammer. Although the agency's Nuclear Science Advisory Council recommends building RIA—at either Michigan State or Argonne National Laboratory in Illinois—its other committees covering fusion energy and high-energy physics are each pushing strongly for even more expensive projects. And that stiff competition is likely to produce losers as well as winners. "In times of tight budgets, you have to make tough decisions," says James Decker, principal deputy director of DOE's Office of Science. In an effort to sway DOE, RIA's supporters point to growing European interest in building a rival facility in Darmstadt, Germany (see p. 1534). "They're moving on a very aggres-

CREDIT: UK MOD/AP

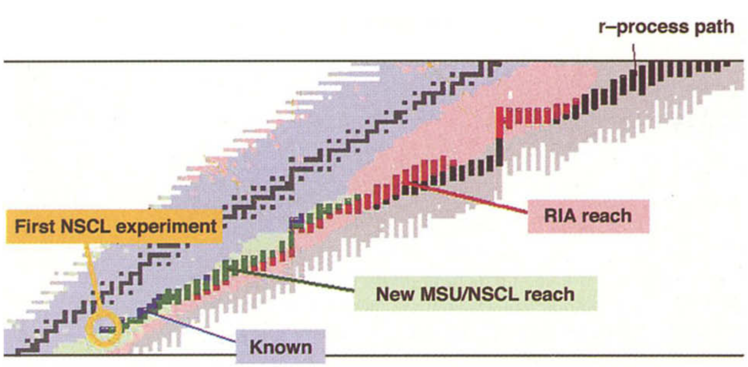
sive and assertive trajectory," warns Gelbke, "but RIA has been on the table for more than 2 years."

Scientists hope that RIA will focus on a crucial final piece of the puzzle of how stars create elements heavier than helium. Physicists already know in great detail how lighter elements such as carbon and oxygen are produced in the nuclear furnaces of stars, which take hydrogens and fuse them into helium and eventually into other elements. But fusion can't create elements heavier than iron, the most stable atom of all, meaning that elements such as gold, lead, and uranium had to be forged in some other way.

Much of it happens in dying stars. After a star exhausts its supply of hydrogen fuel, it flares briefly before burning helium for hundreds of thousands of years. The byproducts of this nuclear furnace are copious amounts of neutrons, which bombard light elements produced by fusion in the aging sun. Under the neutron assault, these atoms capture more and more of the neutrons and become heavier and heavier. When they stray too far from the realm of atomic stability, they decay by spitting out a particle or by converting a neutron into a proton. But the neutrons keep coming, and the nuclei get heavier still—far beyond what normal stars produce with fusion—in what astronomers call the s-process. "The s-process … accounts for roughly half of the heavy elements beyond iron," says Hendrik Schatz, a nuclear astrophysicist at Michigan State University.

By knowing the properties of the elements involved in the s-process and analyzing elements sequestered in ancient meteorites, stellar winds, and other places, scientists have figured out that it occurs in the helium-burning phase of dying stars, says Michael Wiescher, a nuclear astrophysicist at the University of Notre Dame in Indiana: "You can use this information to pin down the site for the s-process." Yet even this knowledge can't account for half the trans-iron elements.

CREDITS: HENDRIK SCHATZ/NSCL/MICHIGAN STATE UNIVERSITY



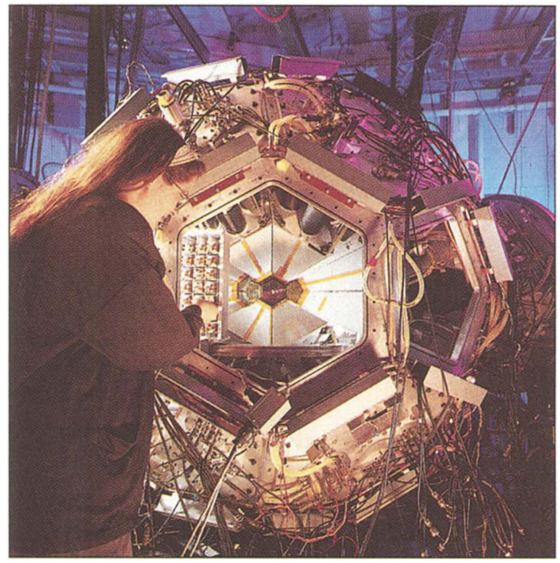
Unknown territory. Only a handful of atoms (dark gray) are stable; those with too many neutrons (below the stable ones) will decay. RIA will investigate these neutron-rich species, especially those involved in the r-process (blue, green, red, and black).

Physicists believe that a different, more rapid form of transformation, known as the r-process, is needed to make the rest. The r-process requires a million billion times as many neutrons as a dying star can churn out, bombarding light atoms with an immense number of neutrons in a matter of seconds. Unlike the slow s-process, in which atoms accumulate neutrons at a leisurely pace over hundreds of thousands of years, the r-process so overwhelms atoms with neutron bombardment that they don't have a chance to decay before having to swallow one neutron after another. The atoms swell in size very rapidly, passing from unstable state to unstable state as they grow. After the bombardment ceases, the products decay into the stable and semistable elements (such as uranium) that dot our solar system.

That's the theory, but scientists are still uncertain what object or event triggers the r-process. The elements involved in the r-process are so neutron-laden that they are very unstable and short-lived, and scientists haven't been able to study them in the lab. "There's a lot of debate going on about where [the r-process] actually occurs," says Wiescher. "You have to have a large neutron flux, a neutron-rich environment, and certain thermodynamic conditions of temperature, pressure, and entropy. Right now, there are two candidates." One candidate is the violent collision of two neutron stars. But physicists think it is more likely that the r-process takes place in the fiery cataclysm of a supernova explosion: the product of either the superdense shock wave that ripples away from the supernova or the enormous "wind" of neutrinos that pushes matter away from the explosion.

Nuclear physicists hope RIA will fill in this knowledge gap. The accelerator will measure the basic properties of very unstable elements, including many of those involved in the r-process. "The r-process species are very far away from stability, but RIA has the intensity and selectivity to reach these," says Schatz. "I think with RIA, we will have a pretty solid understanding of nuclear physics underlying the r-process."

RIA is designed to create these elements in two ways. The first uses a beam of light atoms that strikes a big chunk of a heavy element such as uranium or thorium, shattering the nuclei in the target and creating unstable fragments. The target block is then heated to diffuse out the fragments, which are then sorted and measured. Unfortunately, this method, which is used by existing heavy-ion labs such as ISOLDE at CERN, the European particle physics laboratory near Geneva, and TRIUMF in Vancouver, Canada, can't analyze very short-lived species that decay before the extraction process is complete.



Atom catcher. One of RIA's detectors will look very much like this one at Michigan State's heavy-ion laboratory.

But RIA can use a second method—one pioneered by the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University—that shoots a beam of heavy elements at a thin target of light elements. The heavy nuclei fragment, fly through the target, and are immediately sorted into different species by their mass and charge. Because this method wastes no time with extraction from a thick target, scientists can measure very short-lived species quickly. Once they understand the properties of the elements involved in the r-process, nuclear physicists will be able to figure out what stellar conditions are needed for it to take place. "It has a chance of really solving the [r-process] problem," says Donald Geesaman, the director of Argonne National Laboratory's physics division.

As an added benefit, RIA will be able to supply rare isotopes for other studies, including basic nuclear structure research, nuclear proliferation-related experiments, or even medical applications. "It'll open a whole new world," says Geesaman. "Any isotope you want, you can have."

But only if it's built, of course. DOE's Decker says that no decision on the project is imminent, assigning it a status that makes U.S. supporters uncomfortable. Last week, Germany's Science Council set priorities for major science projects, and a $675 million heavy-ion laboratory is among the experiments that it deemed deserving of attention. This unnamed laboratory, which would be built at the GSI heavy-ion research center in Darmstadt, Germany, has a great deal of overlap with RIA, although Gelbke says it probably won't put the r-process problem to rest; its broader mission means that it wouldn't be able to study quite as many elements as RIA would.

"We're poised and ready to go," he adds. "All we need is a decision." –CHARLES SEIFE

EVOLUTION

A Trigger for the Cambrian Explosion?

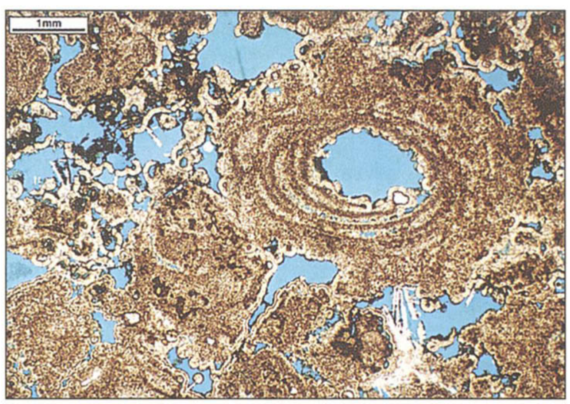
Sediments in Oman provide evidence that an extinction 542 million years ago set the stage for a proliferation of wild and wonderful life forms

Before the Cambrian period began 542 million years ago, life was microscopic, vegetative, or just so odd that it now seems otherworldly. Then, in a geologic moment, an evolutionary explosion littered the fossil record with the recognizable remains of every basic form of animal that we know today. What caused this change is controversial. Some think of the lead-in to this explosion as a "slow fuse" of gradually accumulating genetic traits that finally produced large, complex animals; others believe a "trigger" of some sort set off the mechanism that suddenly produced Cambrian animals.

At last month's annual meeting of the Geological Society of America in Denver, Colorado, sedimentologist John Grotzinger of the Massachusetts Institute of Technology and his colleagues reported the latest evidence of a trigger for the Cambrian explosion: an extinction 542.0 million years ago, possibly brought on when the deep sea disgorged noxious waters. "We do have evidence for point-blank extinction," says Grotzinger. But even in the data-sparse realm of early life, this one page from the fossil record of Oman isn't enough to prove that a near-knockout punch to primitive life set off the Cambrian explosion. Despite the rarity of sediment and fossils preserved from that time, more records must be found.

Forming the Oman record entailed some geologic happenstance; finding it required some lingering crude oil. Late in Precambrian times, what is now Oman on the far eastern tip of the Arabian Peninsula held a deep basin filled with water from the adjacent ocean, a sea much like the Mediterranean today. In the basin's shallower waters, great reefs formed as microorganisms helped precipitate millimeter-scale clots of carbonate, known as thrombolites. But the water level would sometimes fall enough to cut off the sea's shallow connection to the open ocean, the seawater would evaporate, and salt instead of carbonate would be deposited. Six pairs of salt and carbonate layers were laid down in Oman, and, to the Omanis' good fortune, oil eventually filled the spaces (blue in figure) between the carbonate clots.

Enter the age of fossil fuel. Drilling for oil has penetrated all six thrombolite layers. In a drill core provided by Petroleum Development Oman, Grotzinger found two of the late Precambrian's emblematic inhabitants —cone-shaped *Cloudina* and gobletlike *Namacalathus*—throughout the first three thrombolite layers. Apparently, these carbonate-shelled animals of uncertain affinities thrived attached to or lying on top of Oman's carbonate reefs. But in the next three reef deposits, *Cloudina* and *Namacalathus* were gone, even though the abundance of thrombolite would suggest that the living conditions were pretty much as they had been during earlier intervals. To Grotzinger, that's strong evidence that *Cloudina* and *Namacalathus* were gone from the world, not just missing from this little corner of it.



Loser. Did the extinction of *Cloudina* (cross-sectioned as oval) and others trigger the Cambrian explosion?

CREDIT: J. GROTZINGER/MIT

By the best measures of time in this distant era, the apparent extinction comes right at the jump from the Precambrian to the Cambrian. Grotzinger and his colleagues found that the carbon isotopic signature of the first thrombolite layer that lacks the Precambrian creatures is significantly lighter than the signatures of those below it. A similar isotopic shift marks the boundary between the Precambrian and the Cambrian elsewhere in the world. And radiometric dating of volcanic ash layers shows that the shift took less than a million years and occurred by 542.0 ± 0.5 million years ago, within the documented age range of the boundary's carbon isotopic shift elsewhere.

If *Cloudina* and *Namacalathus* were not alone in disappearing, the resulting extinction at the dawn of the Cambrian could have set off an evolutionary explosion, Grotzinger argues. Such an explosion might occur, he says, "if you cleared the playing field [through an extinction] and started over again." Such a dramatic event could open up new possibilities for life in the same way the extinction of the dinosaurs opened the way for mammals. But rather than envisioning an asteroid impact, Grotzinger sees geochemical signs in the Oman cores—similar to those others have seen elsewhere—that oxygen-deficient, carbon dioxide–rich waters welled up into the shallow sea at the same time. That could have been enough to wipe out any marine species not adept at taking up oxygen or fending off the toxic carbon dioxide (*Science*, 1 December 1995, p. 1441).

No one, including Grotzinger, thinks the case for a global Precambrian-Cambrian extinction is closed. "It would be consistent with an extinction," says paleontologist Sören Jensen of the University of California, Riverside, "but you wouldn't want to say it proves it." First, the evidence so far involves only two species at a single place. Second, no extinction this abrupt has been proposed before, notes paleontologist Douglas Erwin of the National Museum of Natural History in Washington, D.C., but "the Omani data provides further support of there having been a biological crisis then. It's certainly an increasingly reasonable idea." Major extinctions mark the other important turning points of evolution that have occurred since the Cambrian explosion, such as the end of the "old life" of the Paleozoic era 250 million years ago. Proving that a trigger set off the most fundamental evolutionary event since life's origin will take some more digging or perhaps drilling. –RICHARD A. KERR