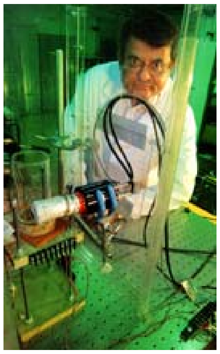
Purdue News

March 2, 2004

Evidence bubbles over to support tabletop nuclear fusion device

WEST LAFAYETTE, Ind. – Researchers are reporting new evidence supporting their earlier discovery of an inexpensive "tabletop" device that uses sound waves to produce nuclear fusion reactions.

The researchers believe the new evidence shows that "sonofusion" generates nuclear reactions by creating tiny bubbles that implode with tremendous force. Nuclear fusion reactors have historically required large, multibillion-dollar machines, but sonofusion devices might be built for a fraction of that cost.



Taleyarkhan with his experiment
Download photo
caption below

"What we are doing, in effect, is producing nuclear emissions in a simple desktop apparatus," said Rusi Taleyarkhan, the principal investigator and a professor of nuclear engineering at Purdue University. "That really is the magnitude of the discovery – the ability to use simple mechanical force for the first time in history to initiate conditions comparable to the interior of stars."

The technology might one day, in theory, lead to a new source of clean energy. It may result in a new class of low-cost, compact detectors for security applications that use neutrons to probe the contents of suitcases; devices for research that use neutrons to analyze the molecular structures of materials; machines that cheaply manufacture new synthetic materials and efficiently produce tritium, which is used for numerous applications ranging from medical imaging to watch dials; and a new technique to study various phenomena in cosmology, including the workings of neutron stars and black holes.

Rusi Taleyarkhan

Taleyarkhan led the research team while he was a full-time scientist at the Oak Ridge National Laboratory, and he is now the Arden L. Bement Jr. Professor of Nuclear Engineering at Purdue.

The new findings are being reported in a paper that will appear this month in the journal Physical Review E, published by the American Physical Society. The paper was written by Taleyarkhan; postdoctoral fellow J.S Cho at Oak Ridge Associated

Universities; Colin West, a retired scientist from Oak Ridge; Richard T. Lahey Jr., the Edward E. Hood Professor of Engineering at Rensselaer Polytechnic Institute (RPI); R.C. Nigmatulin, a visiting scholar at RPI and president of the Russian Academy of Sciences' Bashkortonstan branch; and Robert C. Block, active professor emeritus in the School of Engineering at RPI and director of RPI's Gaerttner Linear Accelerator Laboratory.

The discovery was first reported in March 2002 in the journal Science.

Since then the researchers have acquired additional funding from the U.S. Defense Advanced Research Projects Agency, purchased more precise instruments and equipment to collect more accurate data, and successfully reproduced and improved upon the original experiment, Taleyarkhan said.

"A fair amount of very substantial new work was conducted, " Taleyarkhan said. "And also, this time around I made a conscious decision to involve as many individuals as possible – top scientists and physicists from around the world and experts in neutron science – to come to the lab and review our procedures and findings before we even submitted the manuscript to a journal for its own independent peer review."

The new findings were scrutinized by experts at Oak Ridge.

"There was a great deal of internal review at Oak Ridge National Laboratory before the paper was submitted to the journal for external review," said Lee L. Riedinger, deputy for science and technology at Oak Ridge. "It is clear that Rusi's new data are more significant statistically than his earlier data. This is an exciting result, even if I do not understand the origin of the effect."

Riedinger said new experiments should be conducted to check the findings and to spur further research.

The device is a clear glass canister about the height of two coffee mugs stacked on top of one another. Inside the canister is a liquid called deuterated acetone. The acetone contains a form of hydrogen called deuterium, or heavy hydrogen, which contains one proton and one neutron in its nucleus. Normal hydrogen contains only one proton in its nucleus.

The researchers expose the clear canister of liquid to pulses of neutrons every five milliseconds, or thousandths of a second, causing tiny cavities to form. At the same time, the liquid is bombarded with a specific frequency of ultrasound, which causes the cavities to form into bubbles that are about 60 nanometers – or billionths of a meter – in diameter. The bubbles then expand to a much larger size, about 6,000 microns, or millionths of a meter – large enough to be seen with the unaided eye.

"The process is analogous to stretching a slingshot from Earth to the nearest star, our sun, thereby building up a huge amount of energy when released," Taleyarkhan said.

Within nanoseconds these large bubbles contract with tremendous force, returning to roughly their original size, and release flashes of light in a well-known phenomenon known as sonoluminescence. Because the bubbles grow to such a relatively large size before they implode, their contraction causes extreme temperatures and pressures comparable to those found in the interiors of stars. Researchers estimate that temperatures inside the imploding bubbles reach 10 million degrees Celsius and pressures comparable to 1,000 million earth atmospheres at sea level.

At that point, deuterium atoms fuse together, the same way hydrogen atoms fuse in stars, releasing neutrons and energy in the process. The process also releases a type of radiation called gamma rays and a radioactive material called tritium, all of which have been recorded and measured by the team. In future versions of the experiment, the tritium produced might then be used as a fuel to drive energy-producing reactions in which it fuses with deuterium.

Whereas conventional nuclear fission reactors produce waste products that take thousands of years to decay, the waste products from fusion plants are short-lived, decaying to non-dangerous levels in a decade or two. The desktop experiment is safe because, although the reactions generate extremely high pressures and temperatures, those extreme conditions exist only in small regions of the liquid in the container – within the collapsing bubbles.

One key to the process is the large difference between the original size of the bubbles and their expanded size. Going from 60 nanometers to 6,000 microns is about 100,000 times larger, compared to the bubbles usually formed in sonoluminescence, which grow only about 10 times larger before they implode.

"This means you've got about a trillion times more energy potentially available for compression of the bubbles than you do with conventional sonoluminescence," Taleyarkhan said. "When the light flashes are emitted, it's getting extremely hot, and if your liquid has deuterium atoms compared to ordinary hydrogen atoms, the conditions are hot enough to produce nuclear fusion."

The ultrasound switches on and off about 20,000 times a second as the liquid is being bombarded by neutrons.

The researchers compared their results using normal acetone and deuterated acetone, showing no evidence of fusion in the former.

Each five-millisecond pulse of neutrons is followed by a five-millisecond gap, during which time the bubbles implode, release light and emit a surge of about 1 million neutrons per second.

In the first experiments, with the less sophisticated equipment, the team was only able to collect data during a small portion of the five-millisecond intervals between neutron pulses. The new equipment enabled the researchers to see what was happening over the entire course of the experiment.

The data clearly show surges in neutrons emitted in precise timing with the light flashes, meaning the neutron emissions are produced by the collapsing bubbles responsible for the flashes of light, Taleyarkhan said.

"We see neutrons being emitted each time the bubble is imploding with sufficient violence," Taleyarkhan said.

Fusion of deuterium atoms emits neutrons that fall within a specific energy range of 2.5 mega-electron volts or below, which was the level of energy seen in neutrons produced in the experiment. The production of tritium also can only be attributed to fusion, and it was never observed in any of the control experiments in which normal acetone was used, he said.

Whereas data from the previous experiment had roughly a one in 100 chance of being attributed to some phenomena other than nuclear fusion, the new, more precise results represent more like a one in a trillion chance of being wrong, Taleyarkhan said.

"There is only one way to produce tritium – through nuclear processes," he said.

The results also agree with mathematical theory and modeling.

Future work will focus on studying ways to scale up the device, which is needed before it could be used in practical applications, and creating portable devices that operate without the need for the expensive equipment now used to bombard the canister with pulses of neutrons.

"That takes it to the next level because then it's a standalone generator," Taleyarkhan said. "These will be little nuclear reactors by themselves that are producing neutrons and energy."

Such an advance could lead to the development of extremely accurate portable detectors that use neutrons for a wide variety of applications.

"If you have a neutron source you can detect virtually anything because neutrons interact with atomic nuclei in such a way that each material shows a clear-cut signature," Taleyarkhan said.

The technique also might be used to synthesize materials inexpensively.

"For example, carbon is turned into diamond using extreme heat and temperature over many years," Taleyarkhan said. "You wouldn't have to wait years to convert carbon to diamond. In chemistry, most reactions grow exponentially with temperature. Now we might have a way to synthesize certain chemicals that were otherwise difficult to do economically.

"Several applications in the field of medicine also appear feasible, such as tumor treatment."

Before such a system could be used as a new energy source, however, researchers must reach beyond the "break-even" point, in which more energy is released from the reaction than the amount of energy it takes to drive the reaction.

"We are not yet at break-even," Taleyarkhan said. "That would be the ultimate. I don't know if it will ever happen, but we are hopeful that it will and don't see any clear reason why not. In the future we will attempt to scale up this system and see how far we can go."

Writer: Emil Venere, (765) 494-4709, venere@purdue.edu

Sources: Rusi P. Taleyarkhan, (765) 494-0198, rusi@purdue.edu

James Riordon, (301) 209-3238, riordon@aps.org

Theresa Bourgeois, RPI director of media relations, (518) 276-2840, bourgt@rpi.edu

Purdue News Service: (765) 494-2096; purduenews@purdue.edu

PHOTO CAPTION:
Rusi Taleyarkhan, a professor of nuclear engineering at Purdue University, has led research showing evidence for nuclear fusion reactions in a tabletop experiment. Taleyarkhan is shown here with his experiment in a U.S. Department of Energy facility in Oak Ridge, Tenn., where he conducted the research before coming to Purdue. (U.S. Department of Energy file photo/Lynn Freeny)

ABSTRACT

Additional Evidence of nuclear emissions during acoustic cavitation

R.P. Taleyarkhan[1], J.S. Cho[2], C.D. West[3], R. T. Lahey[3], Jr., R.I. Nigmatulin[4], and R.C. Block[3]

[1]Purdue University, West Lafayette, Indiana 47907, [2]Oak Ridge Associated Universities, Oak Ridge, Tennessee 37830, [3]Rensselaer Polytechnic Institute, Troy, New York 12180,
[4]Russian Academy of Sciences,
6 Karl Marx Street, Ufa 450000, Russia

Time spectra of neutron and sonoluminescence emissions were measured in cavitation experiments with chilled deuterated acetone. Statistically significant neutron and gamma ray emissions were

measured with a calibrated liquid-scintillation detector, and sonoluminescence emissions were measured with a photomultiplier tube. The neutron emission energy corresponded to <2.5 MeV and had an emission rate of up to ~$4X10^5$ n/s. Measurements of tritium production were also performed and these data implied a neutron emission rate due to D-D fusion which agreed with what was measured. In contrast, control experiments using normal acetone did not result in statistically significant tritium activity, or neutron or gamma ray emissions.

● To the Purdue News and Photos Page