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News

Bubble fusion: silencing the hype

***Nature* reveals serious doubts over claims for fusion in collapsing bubbles.**

Imploding bubbles, caught on film emitting light. Taleyarkhan claims they emit energy from fusion too.

Credit: D. Flannigan and K.S. Suslick, University of Illinois at Urbana-Champaign

Nuclear engineer Rusi Taleyarkhan's claims that he had achieved table-top fusion in collapsing bubbles caused a storm when they were first reported in *Science* in 2002. If the effect is real, and could be harnessed, it might one day provide an almost limitless source of energy.

Four years later, Taleyarkhan's work retains an almost magical ability to grab the headlines, most recently in January, when his latest claims were promoted in a press release by the American Physical Society, and Science defended its initial publication of the work in an **editorial** as recently as 3 March. Millions of dollars are being spent trying to repeat the work, including $800,000 from the US Department of Defense. But corroboration remains elusive.

Taleyarkhan and his co-authors vigorously affirm that the effect they have seen is real, and have published several further positive studies - most recently in *Physical Review Letters*, in which they claim to have countered previous technical objections to their work.

Yet there has been no independent confirmation of their results, and an investigation by *Nature* of the circumstances surrounding the experiments reveals serious questions about their validity. Interviews with researchers who have worked closely with Taleyarkhan at Purdue University in the past two years, a re-analysis of his data by a group critical of him, as well as a review by the US patent office, suggest that serious doubts are prevalent in the physics community.

Purdue University did not promote Taleyarkhan's most recent paper to the media. This may reflect the fact that other faculty members at the university, who are trying to repeat the work, have been concerned by Taleyarkhan's actions since he arrived there full-time in 2004. The steps he has taken, they say, include claiming positive results from equipment on which they had seen only negative data, before removing the equipment from their lab altogether (see '**Is bubble fusion simply hot air**').

Brian Naranjo of the University of California, Los Angeles, has now completed an analysis suggesting that the spectrum reported in Taleyarkhan's latest paper as proof of nuclear fusion came instead from the radioactive decay of standard lab material (see '**Bubble bursts for table-top fusion**').

And the US Department of Energy, for whom Taleyarkhan was working when he first reported his claims, has abandoned its patent application relating to bubble fusion, after the patent office said it would throw it out last year (see '**A sound investment?**').

Taken together, the overall message from many people close to this work is that there is no longer any hope that this line of publications will yield a viable fusion energy source. For some this is almost liberating: those sticking with bubble fusion are freer than ever to explore other approaches to it, or to try other kinds of studies on acoustic chambers and the behaviour of collapsing bubbles. For others it is now the end of bubble fusion. There are other kinds of science to be done.

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News

Is bubble fusion simply hot air?

Concerns gather momentum over claims for table-top energy production.

Eugenie Samuel Reich

Rusi Taleyarkhan with his table-top fusion equipment in a lab at Oak Ridge, Tennessee, where he conducted research before coming to Purdue.

U.S. Department of Energy file photo/Lynn Freeny

Dogged by controversy, the idea of bubble fusion needed a boost - and in January this year it seemed to get it. Nuclear engineer Rusi Taleyarkhan, who originally reported the phenomenon in 2002, published fresh results[1] that he claimed answered his critics and reaffirmed that energy can be generated by nuclear fusion taking place in bubbles.

But even as the media were enthusing over this apparent advance, questions were being raised about Taleyarkhan's research at Purdue University in West Lafayette, Indiana. Several of his colleagues there have revealed to *Nature* that their confidence in Taleyarkhan's work has been seriously dented since he assumed his full-time post in their department in 2004.

Faculty members Lefteri Tsoukalas and Tatjana Jevremovic, along with several others who do not wish to be named, say that they now seriously doubt the reality of the bubble-fusion effect. Since his arrival at the university, they say, Taleyarkhan has declined to share the raw data he claims to have obtained in successful experiments on shared equipment. The faculty members add that he has opposed publication of their own negative results and has removed the equipment on which they were trying to replicate his work. "I am very concerned," says Jevremovic.

Bubble fusion is not a crank idea. It is well established that under certain conditions sound waves can force bubbles in a liquid to collapse and produce very high concentrations of energy. The energies inside individual bubbles can get high enough to create a plasma in which fusion could occur. In 2002, Taleyarkhan claimed to have demonstrated this effect, generating energy by fusing the nuclei of deuterium, a heavier isotope of hydrogen, inside collapsing bubbles[2], and followed it in 2004 with further positive results[3].

But his results have been controversial from the start. When *Science* published Taleyarkhan's initial paper, three researchers who peer-reviewed the work took the unusual step of shedding their anonymity to criticize the journal's decision to publish[4]. The three - Seth Putterman of the University of California, Los Angeles, Ken Suslick of the University of Illinois at Urbana-Champaign and Lawrence Crum of the University of Washington in Seattle - argued that Taleyarkhan had not ruled out several potential sources of error in his paper.

Try, try again

Nevertheless, the prospect of a cheap and relatively clean source of energy saw large amounts of money allocated to attempts to repeat Taleyarkhan's work. The US Defense Advanced Research Projects Agency (DARPA) gave Putterman $800,000 to try to reproduce the results, although he has so far not succeeded. Impulse Devices, a company based in Grass Valley, California, that focuses on bubble fusion, claims to be putting at least $4 million into its efforts. And researchers in Argentina have tried to recreate the phenomenon and so far failed.

Tsoukalas, head of the School of Nuclear Engineering at Purdue, was also intrigued by the *Science* paper. "This school has long-standing expertise in fluid mechanics and radiation measurements," he says. "I thought we might reproduce the results and build an expertise in the field."

Tsoukalas led Jevremovic and five others in an effort to replicate bubble fusion. The team followed Taleyarkhan's published method, using acetone in which all the hydrogen atoms had been replaced by deuterium. The formation of bubbles was seeded by exposing the liquid to a source of neutrons, and sound waves were then passed through it to generate bubbles and collapse them. The team looked for radioactive tritium, one of the likely products from the fusion of two deuterium nuclei.

In late 2003, Tsoukalas managed to lure Taleyarkhan away from his position at Oak Ridge National Laboratory in Tennessee, and in the spring of 2004 Taleyarkhan arrived full-time at Purdue. By this time, the team had completed several experimental runs, but had not seen any evidence for bubble fusion.

Once Taleyarkhan had arrived, lab members became increasingly concerned by his actions. Jevremovic says that he would sometimes examine the equipment and claim that it was producing positive results, referring to an oscilloscope that he had. She says that she was uncertain about how the oscilloscope fitted into the experiment so she asked him for the raw data, but never received any. "He said: 'Look, there's a peak', but there was nothing to see," she says. "I started questioning it."

Xu and Butt in a press photo distributed by Purdue University in July 2005.

Credit: Purdue University

Now you see it...

Then one day, in or soon after May 2004, lab members arrived to find that Taleyarkhan had removed the experimental set-up from the communal lab, and taken it to his own lab off-campus. "I was really upset," says Jevremovic, who had been planning further work with the equipment. Although Taleyarkhan had contributed some equipment, the removed apparatus was largely funded by Tsoukalas and his colleagues.

"This made it very difficult to triple-check our results," adds Tsoukalas. But he says a decision was made not to pursue the issue: "This was a newly arrived faculty member and we need an atmosphere of tolerance because that is good for creativity."

By January 2005, the other faculty members had prepared a paper on their negative results, but Taleyarkhan was vehemently against it being submitted for publication. Tsoukalas and the other co-authors acquiesced, partly because of scientific caution over reporting negative results too quickly - without their equipment they couldn't generate any more data - and partly to avoid a split in the faculty.

The researchers were therefore particularly upset when, in July 2005, Taleyarkhan asked the press office at Purdue to issue a press release on "peer-reviewed" and "independent" results that were positive for bubble fusion. The claims raised serious concerns at Purdue because the paper in which the results appear was written by two members of Taleyarkhan's own lab: postdoc Yiban Xu and master's student Adam Butt[5]. Taleyarkhan's claim that there has been "independent confirmation" of his results is repeated in the first sentence of his recent paper in *Physical Review Letters*[1].

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Xu and Butt's paper was also not sent out for anonymous peer review, Nature has established - it was published in a special issue of *Nuclear Engineering and Design* that was co-edited by Taleyarkhan, and it was reviewed by Taleyarkhan's co-editor Günther Lohnert of the University of Stuttgart in Germany.

There are also concerns about the paper itself. It states that tritium was detected during experimental runs at one lab, before "the experiment had to be shifted to a new building off-campus". Xu confirms that the tritium data were taken using the equipment that Tsoukalas and Jevremovic were also working on before it was removed by Taleyarkhan. But Tsoukalas and his team maintain that they never saw any raw data from the equipment that corresponded to a positive signal. "Tritium counts were within one standard deviation of zero," says Tsoukalas.

The exact nature of the data cited by Xu is proving hard to pin down. Xu reported them again, a few months after they were published, when he submitted a paper to the 11th Topical Meeting on Nuclear Reactor Thermal-Hydraulics in Avignon, France. But this time the size of the variation in the radiation counts for the positive tritium runs had slightly decreased, whereas the average for the control runs had become slightly more negative.

Butt, who arrived in Taleyarkhan's lab after the data were taken, has now officially left the lab and has declined to comment. Xu blames the discrepancies on errors that were caused when two analyses became accidentally mixed up, but says that he stands by the paper's conclusions. A slideshow by Taleyarkhan posted on the Internet also shows data from Xu's analysis, but in this case a text box has been moved to obscure a point corresponding to a negative experimental run. When *Nature* attempted to contact Taleyarkhan, he said by e-mail on 22 February that he expected to be very busy for the next ten days. He has not responded since to any questions put to him regarding the points raised in this article.

In light of the growing concerns over Taleyarkhan's work, and his repeated claims of positive results, Tsoukalas says that he and his colleagues have now decided to submit their negative results for publication. On 1 March their paper was with the journal *Nuclear Technology* and was being prepared for peer review.

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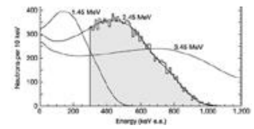
News

Bubble bursts for table-top fusion

Data analysis calls bubble fusion into question.

Eugenie Samuel Reich



The detection spectrum of neutrons from a fusion reaction has a hump, and then dies down to zero.

Data claimed in January to be evidence for bubble fusion are actually a much better match for the radioactive decay of a standard lab source - by a factor of more than 100 million.

That is the key claim in an analysis by physicist Brian Naranjo, who is in the group of Seth Putterman at the University of California, Los Angeles. If correct, it casts serious doubt on the claims made by Rusi Taleyarkhan of Purdue University in West Lafayette, Indiana, that he has produced energy by nuclear fusion in collapsing bubbles in a liquid.

Putterman has been a key critic of Taleyarkhan's work since 2002, when Taleyarkhan first published his claim to have achieved bubble fusion[1]. Putterman and others argue that Taleyarkhan has not been able to rule out several potential sources of error in his experiment. In particular, they were concerned that the source of neutrons Taleyarkhan used to seed bubble formation in the liquid could have been responsible for the neutrons detected during the experiment and cited as evidence for fusion.

In January, Taleyarkhan and his colleagues published further positive results, in which they again cited the detection of neutrons as evidence for bubble fusion[2]. This time, Taleyarkhan sought to allay doubts over the neutron detection by seeding bubble formation with alpha particles rather than neutrons.

Sound footing?

But Naranjo and Putterman say that the spectrum that Taleyarkhan claims proves neutrons were generated by fusion looks nothing like it should given the equipment used. The fusion of deuterium nuclei produces neutrons that have a particular energy of 2.45 mega-electronvolts (MeV). "The published spectrum is totally inconsistent with that of 2.45 MeV neutrons, raising doubt over the fusion claim," says Naranjo.

The spectrum for such neutrons should have a hump in the middle and a sharp cut-off at higher energies. Yet both features are strikingly absent from Taleyarkhan's data, Naranjo says. The probability of getting a spectrum that is such a poor match for neutrons produced by fusion is one in more than 100 million - virtually impossible, Naranjo calculates.

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But the data are a very good match for the spectrum that would be expected if neutrons were produced by the normal fission of a standard lab radioactive source: the decay of californium-252.

That raises a serious question over Taleyarkhan's methodology, because it suggests that an external neutron source was present, although his paper claims that this was not the case.

Another possibility, which Naranjo considered but believes is less likely based on the published data, is that the reported spectrum was produced by cosmic neutrons that had accumulated in the detector over time. But if this was the case, it would not explain why Taleyarkhan consistently saw many more neutrons during the positive experimental runs than during the negative control runs, as he claims. One possibility is that the experimental runs were longer than the control runs, but this would conflict with the method described in the paper, Naranjo says.

Naranjo has submitted his analysis to the **arXiv preprint server** and to Physical Review Letters as a comment on Taleyarkhan's paper, he says. The work is also posted on his own **website**.

Naranjo is familiar with neutron spectra produced by fusion as in April 2005 he co-authored a paper on a table-top fusion device that produces neutrons[3] - although it is not a potential energy source.

Taleyarkhan's most recent paper[2] came with much more data than his previously published works, allowing for more analysis. Naranjo took advantage of the fact that all of the graphs were published in editable form within PDF files, which allowed him to work out the numerical values behind them. Crucially, Naranjo says that he was able to validate his calculations by showing that they produce a very good match to Taleyarkhan's own published calibration data.

Taleyarkhan has so far declined comment on the new claims. Putterman says that Taleyarkhan was made aware of the concerns during a meeting at Purdue on 1 March. Ken Suslick of the University of Illinois at Urbana-Champaign, who also attended the meeting, says that the analysis looks definitive to him. "At the very least it's not fusion, and it looks remarkably like californium," he says.

Problems over Taleyarkhan's work do not change the fact that bubble fusion is a promising idea, nor do they undermine the intrinsic scientific interest in studying the behaviour of collapsing bubbles, Putterman says. But if Taleyarkhan's work is wrong, it would open the field up to a range of different approaches. Taleyarkhan's initial choice of deuterated acetone as a fluid may have been a poor one because it has a high vapour pressure, making it hard to collapse the bubbles. Putterman suggests that using a fluid with a low vapour pressure, such as sulphuric acid, might prove more productive.

But for the time being, Putterman is still being funded by the US Defense Advanced Research Projects Agency (DARPA) to replicate Taleyarkhan's set-up because that is what the prior claim was, says William Coblenz of the agency. "That's the scientific method," says Coblenz, who also attended the recent Purdue meeting. Coblenz declined comment on Naranjo's analysis.

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News

A sound investment?

Rejection leaves bubble-fusion patent high and dry.

Eugenie Samuel Reich

So far, science fiction: the US patent office says there is as yet no reputable evidence for bubble fusion.

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The US patent office has been drawn into the debate over whether bubble fusion has been achieved. In a crushing rejection of a patent application on the phenomenon, patent examiner Ricardo Palabrica concludes that despite the claims for bubble fusion presented in *Science*[1] in 2002, he doesn't believe a word of them. "There is no reputable evidence of record to support any allegations or claims that the invention is capable of operating as indicated," he writes.

In 2003, while at Oak Ridge National Laboratory in Tennessee, nuclear engineer Rusi Taleyarkhan filed the US patent application with his co-author Colin West, on behalf of the US Department of Energy (DOE), which funded their work. It describes the idea of using an acoustic chamber designed by West to produce thermonuclear fusion. In support of the application, Taleyarkhan submitted data from his *Science* paper, in which he reported having observed bubble fusion in such a chamber.

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Palabrica was unimpressed. In his assessment, published in September 2005, he attacks Taleyarkhan's claimed invention as "nothing more than a variation" of the discredited concept of cold fusion first put forward in the late 1980s by Martin Fleischmann and Stanley Pons, and cites reproducibility concerns as a serious obstacle to obtaining a patent. "The statute requires the applicant to inform, not to direct others to find out for themselves [how to reproduce the invention]," he writes.

The examiner refers to press reports about the row that ensued when *Science* published Taleyarkhan's paper despite objections by the scientists who peer-reviewed it, as well as a study by Dan Shapira and Michael Saltmarsh[2], also at Oak Ridge, who had tried and failed to reproduce Taleyarkhan's results.

Examiners would not take controversy alone as a basis for rejecting a patent, says Arnold Silverman, who for 14 years ran the intellectual-property group at the law firm Eckert Seamans Cherin & Mellott based in Pittsburgh, Pennsylvania. But he says that it is not unheard of for a patent examiner who is already sceptical to use other reports to put the burden of proof back on the applicant. "They will challenge the claimed utility of the invention," Silverman says.

Palabrica notes in his rejection that the patent office is aware that the field of fusion research has been particularly prone to erroneous claims, and that for this reason he wanted extra evidence that potential sources of error had been ruled out.

The rejection could have been appealed but in December 2005 the DOE instead abandoned the claim altogether. A version of the patent filed in 2002 at the World Intellectual Property Organization is still under review in many countries.

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