the most he could have hoped for at this point: "We know there is still a long way to go."

The DOE is a major funder of fusion research. But although the United States is bound by an international treaty to provide its share of ITER's costs — a relatively small 9% of the project's budget — it cannot meet its contributions if Congress does not approve them.

**GROWING BUDGET**

The report's recommendations have provoked scepticism on Capitol Hill. Senator Dianne Feinstein of California, the highest-ranking Democrat on the Senate panel that oversees DOE spending, says that the United States cannot afford to keep pace with ITER's growing budget. The DOE estimates that the country's annual contribution, currently US$115 million, will more than double by 2018.

Last year, the Senate proposed to end support for ITER, but backed down during final negotiations with the House of Representatives. This year, it is not clear that ITER will win a reprieve. On 12 May, the Senate approved an energy-funding bill for fiscal year 2017 that cut all spending on ITER. And on 26 May, the House rejected its own 2017 energy-spending bill, which included money for ITER.

Without the United States, ITER would probably survive, says Mark Koepke, a plasma physicist at West Virginia University in Morgantown who leads a government advisory panel on fusion research. But in April, Bigot told US lawmakers that the country's fusion expertise would be difficult to replace. Madia says that the effect of a US exit is impossible to predict: "It makes good cocktail conversation, but no one knows what would actually happen."

***"ITER remains the best candidate today to demonstrate sustained burning plasma."***

ITER's approach to fusion is to trap heavy isotopes of hydrogen in a doughnut-shaped vacuum vessel called a tokamak and heat them to 150 million °C. This should force their nuclei to fuse, releasing vast amounts of energy. Other tokamaks exist, but ITER would be the first to release substantially more energy than was put into the hydrogen plasma.

Begun in 2007, the project was originally due to be completed in 10 years for €5 billion (US$5.6 billion). Observers say that under previous director-general Osamu Motojima, who was in office from 2010 to 2015, the experiment was in denial about slipping deadlines and witnessed a drop in staff morale. After the independent review by Madia, the ITER Council accelerated the transition to a new director-general, nominating Bigot, a French nuclear physicist with extensive management experience, in late 2014.

By November 2015, Bigot's team had presented a revised timetable for the project, and estimated that it would cost an extra €4.6 billion to bring to completion. The team said that the earliest possible date for getting hydrogen plasma to run inside the machine was 2025, and that it would take several more years to inject the heavier hydrogen isotopes tritium and deuterium, and achieve fusion.

In April, an external review from the ITER Council Working Group confirmed that progress had been made on the recommendations of the Madia report, and that the new management had been realistic about the earliest possible date for plasma. But it pointed out that the estimates of costs and the completion date did not take into account possible contingencies.

The latest DOE report recommends funding the cost increases cited by Bigot, but remains sceptical about the schedule. It outlines two funding scenarios: one based on achieving first plasma in 2025, and a more realistic scenario that pushes the date back to 2028.

Bigot's team also proposed a more modest plan, which achieves first plasma on time but delays fusion. This should save money by postponing the parts of construction that are not needed for first plasma, but no one has yet calculated how much. ■

MATHEMATICS

# Maths proof smashes size record

*Supercomputer produces a 200-terabyte proof — but is it really mathematics?*

**BY EVELYN LAMB**

Three computer scientists have announced the largest-ever mathematical proof: a file that comes in at a whopping 200 terabytes, equivalent to all the digitized text held by the US Library of Congress. The researchers have created[1] a 68-gigabyte compressed version of their solution — which would allow anyone with about 30,000 hours of spare processor time to download, reconstruct and verify it — but a human could never hope to read through it.

Computer-assisted proofs too large to be directly verifiable by humans have become common, as have computers that solve problems in combinatorics — the study of finite discrete structures — by checking through umpteen individual cases. Still, "200 terabytes is unbelievable", says Ronald Graham, a mathematician at the University of California, San Diego. The previous record-holder is thought to be a 13-gigabyte proof[2], published in 2014.

The puzzle that required the 200-terabyte proof, called the Boolean Pythagorean triples problem, has troubled mathematicians for decades. In the 1980s, Graham offered a prize of US$100 for anyone who could solve it. (He presented the cheque to one of the three computer scientists, Marijn Heule of the University of Texas at Austin, last month.) The problem asks whether it is possible to colour each positive integer either red or blue, so that no trio of integers $a$, $b$ and $c$ that satisfy Pythagoras' famous equation $a^2+b^2=c^2$ are all the same colour. For example, for the Pythagorean triple 3, 4 and 5, if 3 and 5 were blue, 4 would have to be red. ▶

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NATURE PODCAST

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In a paper[1] posted on the arXiv server on 3 May, Heule, Oliver Kullmann of Swansea University, UK, and Victor Marek of the University of Kentucky in Lexington show that there are many allowable ways to colour the integers up to 7,824 — but when you reach 7,825 or above, it is impossible for every Pythagorean triple to be multicoloured. There are more than $10^{2,300}$ ways to colour the integers up to 7,825, but the researchers took advantage of symmetries and several techniques from number theory to reduce the number of possibilities that the computer had to check to just under 1 trillion. It took about 2 days running 800 processors in parallel on the University of Texas's Stampede supercomputer to zip through all the possibilities. The researchers then verified the proof using another computer program.

The Pythagorean triples problem is one of many similar questions in Ramsey theory, an area of mathematics that is concerned with finding structures that must appear in sufficiently large sets. For example, the researchers think that if the problem had allowed three colours, rather than two, they would still have hit a point where it would have been impossible to avoid creating a Pythagorean triple where *a*, *b* and *c* were all the same colour; indeed, they conjecture that this is the case for any finite choice of colours. Any proof for more colours will probably be even larger than the 200-terabyte 2-colour proof, unless researchers can simplify the case-by-case checking process with a breakthrough in understanding.

Although the computer solution has cracked the Boolean Pythagorean triples problem, it hasn't provided an underlying reason why the colouring is impossible, or explored whether the number 7,825 is meaningful, says Kullmann. That echoes a common philosophical objection to the value of computer-assisted proofs: they may be correct, but are they really mathematics? If mathematicians' work is considered to be a quest to increase human understanding of mathematics, rather than to accumulate an ever-larger collection of facts, a solution that rests on theory seems superior to a computer ticking off possibilities.

In the case of the 13-gigabyte proof[2] from 2014, which solved a special case of a question called the Erdős discrepancy problem, a theory-based solution was eventually found. Mathematician Terence Tao of the University of California, Los Angeles, solved[3] the general problem the old-fashioned way in 2015 — a much more satisfying resolution. ■

1. Heule, M. J. H., Kullmann, O. & Marek, V. W. Preprint at http://arxiv.org/abs/1605.00723 (2016).
2. Konev, B. & Lisitsa, A. Preprint at http://arxiv.org/abs/1402.2184 (2014).
3. Tao, T. Preprint at http://arxiv.org/abs/1509.05363 (2015).


KEITH WHEELER/SPL

Napthalene is one of the chemicals slated for review by the US Environmental Protection Agency.

EXPLAINER

# US chemicals law set for overhaul

*Bill would give government more authority to regulate potentially toxic substances.*

**BY JEFF TOLLEFSON**

The US Congress is poised to overhaul the law that governs the introduction and use of chemicals, in one of the most significant changes to the country's environmental regulation in decades. The update to the 1976 Toxic Substances Control Act (TSCA) comes after more than ten years of debate, and many failed attempts to revamp the law.

The US House of Representatives passed the bill with overwhelming bipartisan support on 24 May. The Senate is expected to approve the measure soon, clearing the way for US President Barack Obama to sign it into law.

*Nature* takes a look at the implications of the historic deal, which will give the US Environmental Protection Agency (EPA) new power to ensure that chemicals — both old and new — are safe.

**Why amend the current law?**

Critics of the TSCA have long complained that the law effectively ties the EPA's hands, preventing the agency from examining the safety of known chemicals and making it difficult to ensure that new ones do not pose undue health hazards.

The law requires companies to register new chemicals before they are used in products and industrial processes, but the default assumption is that all chemicals are safe. Unless the EPA can show that a given chemical poses an unreasonable risk to human health or the environment, that chemical is automatically approved for use. Companies do not have to provide the agency with much information about their chemicals, and the EPA cannot require industry to conduct additional research without solid evidence that a chemical poses a health risk.

**How many chemicals does the EPA regulate?**

Companies introduce about 700 chemicals into the marketplace each year. And 40 years after the TSCA became law, the EPA's chemical inventory lists 85,000 substances. But nobody knows exactly how many of these chemicals are still in use.

The EPA has identified 90 chemicals that merit further investigation, and possibly regulation. But only about 2% of the chemicals in use today have undergone a safety review by government scientists, according to the Environmental Defense Fund, a watchdog group in New York City.

**So, what will change?**

In short, everything. Once the TSCA is