ceiling to collapse. The walls still stand, and the building will eventually be restored – although this is likely to take longer than the ambitious five years initially forecast, and is set to cost hundreds of millions of euros.

But, until then, the interior of the building holds piles of debris: fallen stonework, burnt timbers and damaged metal artefacts, all now available for scientific study. The absence of tourists might also make it possible to use radar to probe the foundations, which have been little investigated before. Even some parts of the structure that were largely undamaged are now more accessible for inspection, says metals specialist Philippe Dillmann of the CNRS Laboratory for Archaeomaterials and Alteration Forecasting in Gif-sur-Yvette, who is coordinating the project with Regert.

### Architectural investigations

The CNRS project will focus on seven topics: masonry, wood, metalwork, glass, acoustics, digital data collection and anthropology. In all, the effort will involve more than 100 researchers in 25 laboratories and will last for 6 years.

Gallet's team will study Notre-Dame's stones to identify the quarries that supplied them and "reconstruct the supply networks and the economy of the site". Studying the mortar used to bind the stones together could reveal how different compositions were used for the various structural elements – vaulting, walls and flying buttresses. A better knowledge of the historical materials could inform choices made in restoration, says Gallet.

The team will also analyse weaknesses in the remaining structure caused by the high temperatures of the fire, and by the fall of masonry and the water used to extinguish the flames. A radar study will determine how solid the foundations are before restorers erect scaffolding to allow them to dismantle the unstable remnants of the nineteenth-century spire.

Meanwhile, a team of about 50 will focus on Notre-Dame's famous woodwork – especially the timbers in the roof space above the vaults, dubbed the forest – which has either burnt away or lies charred in the nave. These blackened remains could be tremendously valuable to researchers.

"The burnt structure constitutes a gigantic laboratory for archaeology," says dendrologist Alexa Dufraisse of the National Museum of Natural History in Paris, who will lead the multidisciplinary wood team.

"Wood is an extraordinary source of information," says Regert. Initial observations have confirmed that the 'forest' is made of oak, but studies will pinpoint the exact species used and give researchers clues about the techniques and tools of medieval timber construction.

Tree-ring dating of timber beams could reveal the year and location in which the trees were felled, filling in gaps in knowledge about the sequence of construction. "Each tree records within its tissues the environment in which it has grown," says Dufraisse. This kind of study "could never have been conducted without the destruction of the structure by fire", she says.

In particular, says Regert, the wood is a climate archive. "Isotopic analyses of oxygen and carbon in the rings make it possible to determine the temperature and rainfall over time," she says. The trees used in Notre-Dame grew between the eleventh and thirteenth centuries, during a warm period known as the medieval climate optimum, offering a reference period for natural climate warming to compare with anthropogenic warming today.

**"The burnt structure constitutes a gigantic laboratory for archaeology."**

### Access all areas?

Collecting and excavating the materials for analysis is challenging. There are three main piles of debris – in the nave, the north transept and the crossing between the two – as well as material still on top of the remaining vaults. But these are currently off-limits to people for safety reasons, Dillmann says – so robots and drones must do all the collecting. Some of this material might ultimately be reused in restoration.

The collection and analysis will need to be documented precisely and thoroughly. Livio de Luca, a specialist in digital mapping of architecture at the CNRS's Mixed Research Unit in Marseille will lead a team dedicated to creating a "digital ecosystem" that summarizes both the scientific research and the current and previous states of the cathedral, drawing on the work of scientists, historians, archaeologists, engineers and curators – and perhaps even on old tourist photos of the structure.

"It will be like a 'digital twin' of the cathedral, able to evolve as the studies progress," de Luca says. It will include online models for 3D visualization of the building and its attributes, created from billions of data points, with the history and evolution of the structure superimposed on the spatial map.

As well as deepening researchers' understanding of this monumental building, Regert hopes that the scientific studies will be useful when its ravaged vaults rise again. The results, she says, might "illuminate the choices that society will have to make for the restoration".

# WHAT CRISPR-BABY PRISON SENTENCES MEAN FOR RESEARCH

## Chinese court sends strong signal by punishing He Jiankui and two colleagues.

**By David Cyranoski**

A Chinese court has sentenced He Jiankui, the biophysicist who announced that he had created the world's first gene-edited babies, to three years in prison for "illegal medical practice", and handed down shorter sentences to two colleagues who assisted him. The punishments put to rest speculation over whether the Chinese government would bring criminal charges for an act that shocked the world, and they are likely to deter others from similar behaviour, say Chinese scientists.

There has been much speculation about whether other scientists would follow in He's footsteps, especially given the relative ease of using the most popular gene-editing tool, CRISPR–Cas9. But the punishments are "definitely a deterrent to similar misconduct in China", says Wei Wensheng, a gene-editing researcher at Peking University in Beijing.

On 30 December, a court in Shenzhen announced that He and two colleagues had flouted regulations and research ethics by altering genes in human embryos that were then implanted into two women, according to Xinhua News Agency. One woman gave birth to twin girls in late 2018; the court said a third baby has been born but did not say when, a revelation that fits with He's claim in November 2018 that a second woman had been implanted with a gene-edited embryo.



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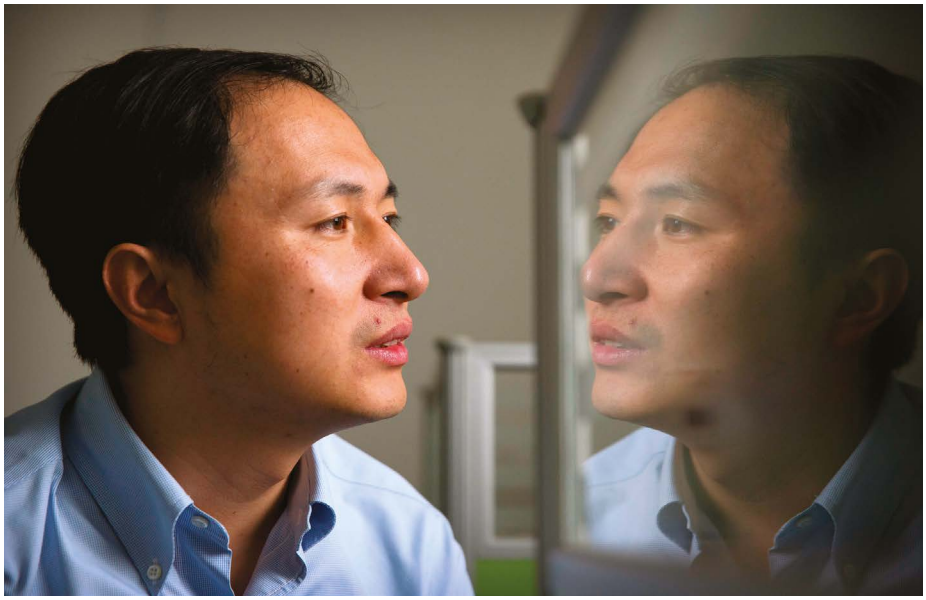

MARK SCHIEFELBEIN/AP/SHUTTERSTOCK

He Jiankui stunned the world when he declared that he'd created the first gene-edited babies.

The court fined He 3 million yuan (US$430,000). Collaborators Zhang Renli and Qin Jinzhou received less severe punishments.

The health ministry has also banned the researchers from working with human reproductive technology again, and the science ministry has banned them from applying for research funding, according to Xinhua.

Scientists in China who are currently researching into CRISPR's potential to treat various genetic diseases by modifying cells other than those of embryos say that they fear He's actions might have a detrimental effect on their work, too, even though it is not as ethically contentious. He shocked the world's scientists in November 2018 when he announced that his team at Southern University of Science and Technology in Shenzhen had used CRISPR to edit DNA in human embryos to make them less susceptible to HIV. The edits were designed to disrupt a gene that encodes a protein allowing HIV to enter immune cells.

Scientists condemned He's actions, saying that gene-editing technology was too premature to be used for reproductive purposes. They also said the experiment was problematic because it risked introducing a mutation with potentially harmful effects while offering little benefit — the babies were not at high risk of contracting HIV. In the wake of the scandal, researchers called for a moratorium on gene editing in embryos and germline cells.

At the time, Chinese law academics told *Nature* that He could face a range of criminal charges, including practising medicine without adequate qualifications, forging ethics documents and skirting laws banning the use of assisted reproductive technologies in people with HIV. He was fired by his university in January last year.

The court's announcement puts to rest the suspicions of some researchers that the government would not bring a criminal case against He because of the increased media attention it would generate, says Tang Li, a science-policy researcher at Fudan University in Shanghai. Discussion of He's experiments was widely censored on Chinese social media. But Tang says the disclosure of the court's result demonstrates China's commitment on research ethics. This is a big step forward in promoting responsible research, she says.

Although an unpublished manuscript describing the experiments lists ten authors, according to *MIT Technology Review*, He, Zhang and Qin are the only ones to face penalties so far. The manuscript says Zhang "performed the human embryo microinjections", *MIT Technology Review* reports. Zhang, who was affiliated with the Guangdong Academy of Medical Sciences and Guangdong General Hospital in Guangzhou at the time of the experiments, has been sentenced to two years in prison and fined one million yuan. Qin, an embryologist at Southern University of Science and Technology who was named as the applicant on the experiment listed on China's clinical-trial website, was given an 18-month suspended prison sentence and fined 500,000 yuan, according to Xinhua. Wei says it is unlikely that He will work again as a researcher at a Chinese institution.

The trio's punishments send a powerful message to other researchers doing any type of gene-editing work in clinical trials in China, says Lu You, an oncologist at Sichuan University in Chengdu. His team was the first to test CRISPR gene-editing in humans, in a clinical trial that modified adult — not embryonic — cells taken from people with lung cancer (see page 156). "If I was a newcomer, a researcher wishing to start gene-editing research and clinical trials, the case would be enough to alert me to the cost of such violations," he says.

Q&A

AUBREY GEMIGNANI/NG IMAGES/ALAMY

## Wanda Diaz Merced

**Astronomy is inextricably associated with colourful images of the cosmos. But Wanda Diaz Merced says that neglecting senses other than sight can mean missing out on discoveries. Diaz Merced, an astronomer at the International Astronomical Union (IAU) Office for Astronomy Outreach in Mitaka, Japan, is a pioneer of sonification, a technique that converts aspects of data, such as frequency, into audible elements. It could help astronomers to avoid biases from interpreting data only visually, argues Diaz Merced, who lost her sight in her twenties. At an IAU meeting on equality and diversity in Mitaka last December, Diaz Merced spoke to *Nature* about the approach.**

**How did you begin working on sonification?**
As an intern at NASA in 2005, I created a tool to map astronomical data into sound — pitch, rhythm and volume. In my 2013 PhD dissertation, I proved that it is useful.

**How did you do that?**
I presented users with spectral data and asked them to look for a double peak that indicates a black hole. People tried to identify signals using vision only, audio only and by combining vision and sound. We found that combining audio with visual interaction was the most sensitive way.

**How can sonification be used?**
It can help us to study the habitability of an exoplanet, by understanding how high-energy rays interact with its magnetic field or atmosphere. Such interactions cause fluctuations of electromagnetic emission from the star that vary with frequency.

**Are astronomers using this approach?**
People are making a bit more of an effort. My collaborators and I are analysing and developing sonification software designed around the user's experience. Now we have to provide the field with the evidence to help researchers to change their mindset.

**Interview by Elizabeth Gibney**
This interview has been edited for length and clarity.



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