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FINAL REACTOR Werner Heisenberg's last wartime experiment, called B8, used 664 uranium cubes suspended in deuterated water as fuel. Shown here is a replica of B8's uranium pile, on display at the Atomkeller Museum, in Haigerloch, Germany.

NUCLEAR FORENSICS SOLVES NAZI MYSTERY

Analysis of World War II-era uranium samples suggests that Germany was nowhere near developing an **ATOMIC BOMB**

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TODAY'S NUCLEAR forensic scientists are typically concerned with detecting radioactive materials being smuggled across borders or tracking down the facilities where those materials originated. But recently, nuclear scientists turned their investigative skills to a nagging question from the annals of science history: During World War II, were the Germans close to achieving a working nuclear reactor?

By analyzing a uranium cube uncovered in the 1960s that had been used in Germany's nuclear program during the war, the scientists—led by Maria Wallenius of the European Commission's Institute for Transuranium Elements, in Karlsruhe, Germany—determined that the Germans weren't even close (*Angew. Chem. Int. Ed.* 2015, DOI: 10.1002/anie.201504874).

The uranium cube in question was suspected to be part of famed physicist Werner Heisenberg's last wartime experiment, called B8, which took place in March 1945. In that experiment, carried out near Haigerloch, Germany, 664 uranium cubes suspended in deuterated, or "heavy," water were used as fuel. The U.S. military's Alsos Mission recovered most of those cubes in April 1945. But a few of them went missing. Two decades later, several uranium cubes—presumed to have been part of B8—were discovered in southern Germany.

In addition to analyzing one of the cubes, Wallenius and coworkers also analyzed a uranium plate that Heisenberg and his collaborator Karl Wirtz had used in a different reactor geometry. Heisenberg and Wirtz switched to cubes after they learned that the more compact shape worked better.

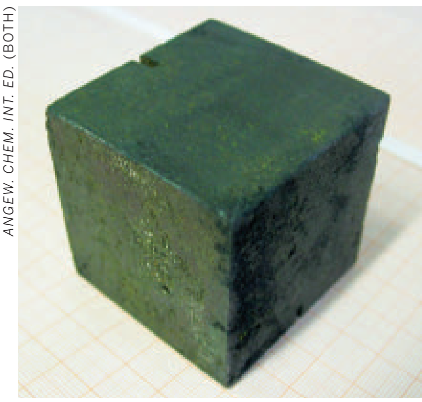
Wallenius and her group had a number of questions about the materials they wanted to answer. Where did the ore used to produce the plate and cube come from and when was it processed? Were the samples enriched in uranium-235, and had they been exposed to a major source of neutrons? The answer to that last question, in particular, would help them figure out whether Germany was close to achieving a sustained chain reaction and, thus, a bomb during World War II.

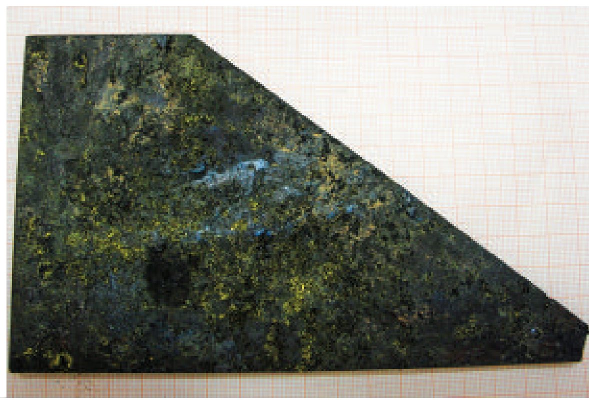
The researchers found evidence to help answer each of those questions by determining different isotope ratios within the materials.

TO DETERMINE THE SOURCE of the ore, they measured the strontium isotope ratio and the pattern of rare-earth elements in the cube and plate and compared them to samples of ores from uranium mining regions that Germany was known to have had access to during the war: the Joachimsthal region in the former Czechoslovakia and the Shinkolobwe mine in the former Belgian Congo. Germany gained access to uranium from Shinkolobwe after it seized Belgium's uranium supply. Measurements taken by Wallenius and her group suggest that both the cube and the plate were made of uranium from Czechoslovakia.

To date the materials,

FUEL The uranium cube and plate shown below on millimeter-grid paper were part of the German wartime nuclear program.





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they used the ratio of thorium-230 to uranium-234 to determine the last time the uranium underwent chemical processing. Such separations typically remove impurities and decay products such as thorium-230. The isotope ratios pin the dates to late 1943 for the cube and mid-1940 for the plate, suggesting that the samples were in fact part of Germany's nuclear program during World War II. They also help confirm the order in which the Germans adopted various reactor designs—first plates, then cubes.

From the ratios of the various uranium isotopes— ^{234}U, ^{235}U, ^{236}U, and ^{238}U— Wallenius and coworkers learned that the samples were not enriched in ^{235}U. Increased levels of this low-abundance, fissionable form of uranium would have made it easier to sustain a nuclear chain reaction.

The amount of another uranium isotope, ^{236}U, taken together with the amount of plutonium-239, serves as an indicator of a sample's past neutron bombardment. This is because ^{236}U forms when ^{235}U captures neutrons, and ^{239}Pu forms when ^{238}U captures neutrons and undergoes beta decay. If the samples had been exposed to a large number of neutrons, as would be found in a working nuclear reactor, their levels of ^{236}U and ^{239}Pu would have thus been elevated relative to their natural abundances.

THE AMOUNT OF ^{236}U in the samples was so small that Wallenius and her coworkers couldn't detect it with their instrumentation and had to send the samples to Australia and Austria to be measured by accelerator mass spectrometry, a more sensitive technique.

Not only were the levels not elevated, the ^{239}Pu level was even lower than would be expected naturally. Wallenius suspects that the low ^{239}Pu resulted from the chemical separations used to process the ore.

"When uranium is chemically processed, most of the other elements are removed," she says. "That means also at least some of the plutonium coming from nature was removed."

These findings help bolster the argument that Germany was not on the verge of having a working reactor during World War II. "The report corroborates the observations of the Alsos Mission's team and longheld assumptions by Manhattan Project historians about the fledgling efforts made to develop an atomic bomb under Nazi Germany," says Cynthia C. Kelly, president of the Atomic Heritage Foundation, in Washington, D.C.

For now, forensics has wrung all the information it can from these samples. But Wallenius doesn't rule out returning to them in the future. "Nuclear forensics is still an evolving discipline," she says. "We continue to develop or look at new parameters that may tell us more of the history of our nuclear forensic samples." ■