Slender and Elegant, It Fuels the Bomb

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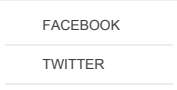
Published: March 23, 2004



There was no breakthrough, no eureka, no flash of insight. It happened slowly, the advances gradual until what Dr. Gernot Zippe and his colleagues had invented was a compact, almost elegant device for collecting uranium's rare U-235 isotope.

The feat might have remained obscure, except that it helped define the nuclear era: by the 1960's, Zippe-type machines had become the easiest way to make fuel for reactors as well as weapons of terrifying power, for lighting cities or destroying them.

The invention was the uranium centrifuge, and around the world, millions of them now spin in high-security plants often ringed by barbed wire.

If a chief inventor has any regrets, he keeps them private. In a recent interview, he was philosophical about his team's brainchild, saying nations had the responsibility to determine whether the work would ultimately be judged good or evil.

"With a kitchen knife you can peel a potato or kill your neighbor," Dr. Zippe (pronounced TSIP-eh) said by phone from Munich, where at 86 he still works occasionally and flies off to international meetings. "It's up to governments to use the centrifuge for the benefit of mankind."

And benefits there are. Nuclear reactors, with Zippe-type centrifuges often making their uranium fuel, now generate about 16 percent of the world's electricity. That figure may rise in the decades ahead as worries grow about global warming and oil shortages.

But news of Dr. Zippe's invention has recently centered on the dangers of its illicit spread. Experts warn that it may put nuclear weapons into the hands of terrorists or states sympathetic to them.

Last month, a Pakistani nuclear expert, Abdul Qadeer Khan, admitted running a vast smuggling ring that had supplied at least three nations with Zippe-type centrifuges. It appears to be history's worst case of nuclear proliferation.

While nations congratulate themselves for exposing the network, private experts say the secretive centrifuge design at the heart of the illegal trade is still on the loose and the dangers of its misuse are far from over.

"It's small and you can procure the needed items in secret without being detected," said David Albright, president of the Institute for Science and International Security, an arms control group in Washington. "You end up with a small plant that's very hard to find."

The world may be in for an unsettling time if the future of the Zippe centrifuge is as surprising as its past. The tale of its development is full of striking twists, and no little sweat.

"It was very hard work," said Houston G. Wood, a centrifuge expert at the University of Virginia. "Problems of great difficulty had to be solved."

Born and raised in Austria, Dr. Zippe studied physics at the University of Vienna in the

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30's and served in the German Luftwaffe as a flight instructor and a researcher on radar and airplane propellers. In 1945, the Russians took him as a prisoner to a special camp for the technically adept.

Moscow was desperate to catch up with Washington in nuclear arms. The hardest part was not the design but getting the fuel. Like all nuclear aspirants, Russia hoped to rearrange nature.

The work centered on isotopes, forms of the same element whose nuclei have different numbers of neutrons. The most prevalent isotope of uranium, which accounts for 99.3 percent of natural uranium, is U-238, with 146 neutrons. It is ever so slightly heavier than U-235, which has three fewer neutrons and accounts for just 0.7 percent of uranium in nature.

But U-235 is highly prized because it easily splits in two to produce bursts of atomic energy. When natural uranium is enriched to contain about 5 percent U-235, it can fuel nuclear reactors; to about 90 percent, atom bombs.

The Russians put Dr. Zippe and other German prisoners of war to work making centrifuges to obtain the rare U-235 isotope. The Americans had tried, but had turned to other methods that were quite bulky, arduous and costly.

The Russian team realized that uranium centrifuges would have to be linked up by the hundreds or thousands so that each could make tiny increases in the U-235 output, slowly raising the concentration. And to be economic and productive, the machines would have to spin continuously for years.

Centrifuges are common devices in industry and medicine that spin fast to separate materials of differing masses -- for instance, blood cells from serum. Though they sound exotic, they are simple in principle. A washing machine on spin cycle is a centrifuge, its whirl creating artificial gravity that separates water (heavy) from clothes (light).

A good washing machine spins about 15 revolutions per second. The Russians -- to have any hope of exploiting the minute differences in the masses of U-235 and U-238 in order to separate the nearly identical substances -- needed centrifuges that spun about 100 times as fast, near the speed of sound.

"Everybody was laughing and said, 'This will never work,' " Dr. Zippe recalled. "I was a young man. I had no idea how to do it. But I decided to do my best."

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