Iraq's Bomb Program: A Smoking Gun Emerges

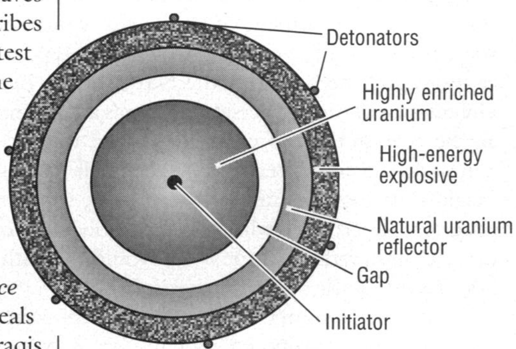
A report unearthed by UN inspectors provides details of the design but indicates key problems remained to be solved

UNITED NATIONS INSPECTORS COMBING through thousands of pages of reports confiscated from a building in Baghdad in September have come across a "smoking gun"—a 17-page document that details the status of Iraq's nuclear weapons program shortly before the invasion of Kuwait in August 1990. The report, which is now making the rounds of nuclear weapons experts in the West and has been made available to *Science*,* leaves no doubts about Iraq's intent. It describes efforts on a broad front to design and test components of a bomb similar to the device dropped on Nagasaki in 1945, but with a core made from enriched uranium rather than plutonium. It contains no evidence, however, that Iraq was working on a hydrogen bomb, as has been widely reported.

Weapons experts consulted by *Science* are impressed by what the report reveals about the level and range of effort the Iraqis were putting into the program. The report "shows that they undertook an expensive and thoroughly well-planned nuclear weapons development effort," says Theodore Taylor, who worked on bomb design at Los Alamos in the 1940s and '50s. But several experts, including Taylor, said the document indicates that parts of the program were still at a relatively early stage and that the Iraqis did not appear to be at the point where they could put a bomb together—even if they had access to sufficient fissile material (see box). "It was not a case of there but for the grace of God they would have had a bomb. But it does show they were working very hard to get one," says J. Carson Mark, former head of the theoretical division at Los Alamos National Laboratory.

The document, part of a cache of reports removed from the Iraqi Atomic Energy Commission by a team from the International Atomic Energy Agency (IAEA), is a progress report for the Al-Athir plant near Baghdad from 1 January to 31 May 1990. IAEA has identified the plant as "the heart of Iraq's nuclear weapons program," says David Kyd, a spokesman for the agency.

Western experts have concluded from the report that Iraq was intending to build a so-called implosion bomb, a device with a spherical core of highly enriched uranium surrounded by a "reflector" consisting of a shell of natural uranium. Conventional high explosives would be wrapped around the uranium shell to form an explosive "lens" that would direct pressure toward the center of the device, and detonators would be arrayed around the surface. Embedded in the core itself would be a so-called initiator, made of polonium-210 and beryllium separated by a layer of gold.



D. DEFRANCESCO

The core of Iraq's efforts. *Detonation of outer explosive layer focuses shock wave on the core, compressing it to criticality.*

The key to such a device is to produce a uniform explosion in the outer layer of high explosives so that a shock wave travels inward, squeezing the uranium reflector and compressing the enriched uranium core until it becomes supercritical. The shock wave would also destroy the gold barrier between the polonium-210 and beryllium, which would generate an intense burst of neutrons to help trigger the chain reaction.

The Nagasaki bomb was designed this way, but the Iraqis may have been attempting to add a key refinement. From some of the theoretical calculations described in the report, it appears that they were planning to make a "levitated" device, with a gap between the core and the reflector. The shock wave would accelerate across the gap and produce greater compression of the core. According to one expert who asked not to be named, this design was not used in the Nagasaki bomb because the designers wanted to be conservative, but it was validated in tests after the war. The advantage is that it allows the use of a smaller amount of fissile material.

The report indicates that Iraqi bomb designers were working on a crucial set of equations to describe the relationships between pressure, temperature, and density of uranium—key determinants to predict how the core and reflector would behave as the

How Much Uranium?

While Iraqi scientists were working on the design and testing of components of an atomic bomb, the key problem facing the effort was to obtain enough highly enriched uranium for the core. Experts estimate Iraq would need at least 20 kilograms for the type of weapon it was planning. At the start of the war, Iraq was known to have 12.3 kilograms of highly enriched uranium (93% U^{235}) supplied under safeguards by France for the Osirak reactor that had been bombed by Israel in 1981, and a supply of slightly less enriched uranium (80%) from the Soviet Union for a research reactor at Tuwaitha.

In April, Iraq informed the International Atomic Energy Agency (IAEA) that it had on hand 13.6 kilograms of the 80% material and less than half a kilogram of the 93% material that had been unirradiated, plus 3.93 kilograms of 83% and 11.17 kilograms of 93% that had been partially irradiated. The remainder was listed as "irradiated," which would make the fissile material difficult to extract quickly. According to Johan Molander, an official with the United Nations special commission that is overseeing the dismantling of Iraq's nuclear weapons capability, these fuels have been accounted for and are being removed from Iraq.

That leaves clandestine production as the most likely source of highly enriched uranium for the bomb program. Iraq is now known to have aggressively pursued a 1940s era technology based on calutrons and a broad range of other avenues, including chemical processing. According to Molander, the UN's best estimate is that 3 kilograms of fissile material were produced in this program, but it was ready to expand rapidly. "There is no assessment that says it would have taken longer than 18 months" to produce sufficient quantities of fissile material, he says. ■ C.N.

*The report was described in detail in the 24 October edition of the Dutch newspaper *NRC Handelsblad*, which made it available to *Science*.

shock wave implodes the material. According to Mark, an expert in this area, the status report "indicates a fairly early stage in their progress through a series of updates."

While they were working on the theory, Iraqi scientists were also conducting direct tests of the behavior of materials under extreme temperature and pressure, and the report says they had conducted 20 tests of explosive lenses "aimed at measurement of the homogeneity of the wavefront." A smooth wavefront is essential to compress the core evenly, otherwise it would blow apart. Concludes Mark: "It doesn't sound like they've got nice, smooth wavefronts yet." They also appear to have lacked a flash x-ray machine needed to take pictures of the material as it compresses, though the report indicates they were working on such a system.

Iraqi researchers appear to have been doing well, however, in their production of key materials. The report states that they had produced 6 milligrams of polonium-210 by irradiating bismuth in a small Soviet-supplied reactor—more than enough for one initiator, according to Mark. They had also produced small amounts of plutonium isotopes, apparently for studies of alpha-emitters, by processing irradiated fuel. And 254 kilograms of uranium metal had been produced in the laboratory and researchers had drawn up plans for a production facility.

As for the crucial electronic systems to fire the detonators, the report says a miniaturized version of a cabling system to provide power simultaneously to 32 detonators had been developed. That's the same number of detonators used in the Nagasaki bomb, according to physicist Thomas Cochran, a nuclear expert at the Natural Resources Defense Council. Researchers were also working on the development of high-speed switches and capacitors that could not be obtained commercially because of export controls.

There is one element of the Iraqi plan that may offer a small measure of relief to its neighbors. Even if Iraqi scientists had solved all these problems, the device they were planning would have been hefty, perhaps weighing as much as a ton, Cochran estimates. That would make it too heavy for Iraq's Scud missiles, which means it would probably have to be delivered by a bomber. The difference may not be trivial: While Saudi Arabia and Israel both possess effective antiaircraft defenses, an Israeli expert is now claiming that, contrary to press accounts, not a single Scud warhead was intercepted by U.S. Patriot missiles loaned to Israel during the war. ■ COLIN NORMAN

With reporting by Karel Knip and Felix Eijgenraam of NRC Handelsblad *in Rotterdam.*

Ozone Loss Hits Us Where We Live

The news about Earth's ozone layer just keeps getting worse. Three weeks ago, NASA researchers reported that the ozone hole over the Antarctic hit a record depth this year (*Science*, 18 October, p. 373). Now comes the United Nations Environment Program, together with the World Meteorological Organization, with an even more distressing assessment of the state of the ozone layer. For the first time, the 80-member UN panel said, measurements show the ozone shield is eroding over temperate latitudes in summer, exposing crops and people to a larger dose of ultraviolet light just when they are most vulnerable.

For a small group of atmospheric modelers, though, the bad news is bittersweet. Four months ago, in the 11 July *Nature*, Jose Rodriguez, Malcolm Ko, and Nien Dak Sze of Atmospheric and Environmental Research (AER) in Cambridge, Massachusetts, predicted summertime ozone losses of just the magnitude the UN panel has now reported: about 3% over the past decade for northern temperate latitudes. Ozone modelers are encouraged by the agreement, particularly because other models are now yielding the same result, according to Michael Prather of the NASA's Goddard Institute for Space Studies in New York, who wrote the UN report's chapter on modeling.

The AER modeling effort was spurred by earlier measurements showing a serious erosion of ozone at midlatitudes, mainly in winter. In 1988, an analysis of data collected from the ground showed that ozone levels at the latitude of the United States were dropping by about 1% to 3% per decade; last April, an analysis of measurements from the satellite-borne Total Ozone Mapping Spectrometer (TOMS) boosted that figure to between 4% and 5% (see *Science*, 12 April, p. 204). Those findings raised the question: What mechanisms could be driving the midlatitude losses?

The fact that the losses seemed to be concentrated in winter suggested one possibility. The winter ozone losses at the poles are driven by chemical reactions taking place on the surface of ice crystals in polar stratospheric clouds. Such clouds don't form at temperate latitudes. But some researchers suggested that masses of air already depleted in ozone or enriched in reactive chlorine by the chemistry in the polar clouds might be escaping to temperate latitudes during the winter.

Laboratory experiments, though, suggested another possibility: that some of the reactions that destroy ozone at the poles could also take place on tiny droplets of sulfuric acid, like the ones that form a thin haze in the global stratosphere. Could it be that these sulfate particles, which originate from volcanic eruptions and other sources, were filling the same niche in the temperate latitudes as the ice particles at the poles?

The answer, according to the AER team, was yes. When the researchers worked the laboratory findings into their computer model of stratospheric chemistry and dynamics, they found that the sulfate-hosted chemistry could account for about half the wintertime losses of ozone in midlatitudes. That still leaves room for mixing out of the pole to be contributing, notes Rodriguez.

Then came a surprise: While the model results for winter were not unexpected, those for summer were. Contrary to existing data, the model predicted substantial ozone losses. "When we submitted the paper to *Nature* we felt almost apologetic," Rodriguez recalls.

No longer. By combining the data sets from TOMS and from ground-based detectors, the UN panel was able to detect a clear signal of summertime ozone losses, a success that panel member Michael Kurylo of NASA attributes to the longer span of the measurements and improved calibration of the TOMS instrument. The 3% loss over the past decade at the latitude of New York may sound bad, but Buenos Aires and Sydney have it even worse, with losses of about 5%. And based on projections of how fast chlorine will continue to build up in the stratosphere in spite of the Montreal agreement to phase out ozone-destroying chlorine compounds, the report predicts additional losses of about the same magnitude by the turn of the century.

Ozone specialists point out that the agreement of the model results with the trend seen so far doesn't mean the models are really mimicking the chemistry responsible for the ozone loss. "It doesn't prove cause-and-effect," says panel member Richard Stolarski of NASA's Goddard Space Flight Center in Greenbelt, Maryland. Nevertheless, it is a gratifying result for the modelers, who have a history of scrambling to explain observations—not of anticipating them. Says panelist Susan Solomon of the National Oceanic and Atmospheric Administration in Boulder: "For once, we were ahead of the game." ■ TIM APPENZELLER