DETECTING THE THREAT

DARPA's Role in Confirming the Integrity of the Partial Nuclear Test-Ban Treaty

By J.R. Wilson

"The partial nuclear test ban was, of course, the first real success leading to an end of the Cold War … and I think ARPA's role was important in having prepared the services to say, 'Yes, we can assure the safety of the country in a nuclear test-ban environment.'"
– Robert Sproull, DARPA director, 1963-1965

The 1957 launch of Sputnik is normally cited as one of the prime movers behind the creation of the Defense Department's (DoD's) Advanced Research Projects Agency. But it was another Cold War concern centered on the Soviet Union that was at least as important for the new agency's first quarter-century: nuclear-test detection.

"In those days, the national interest was defense and the Russians – and technology was believed to be a primary factor in our security," Jack Ruina, DARPA's third director (1961-1963), recalls. "And if the Russians did one test more than we did or did a test that we didn't understand, we gave it tremendous importance."

The technologies DARPA pursued would, in the decades following its creation, make possible a series of nuclear test-ban treaties and provide vital intelligence on what every member of the expanding nuclear club was doing.

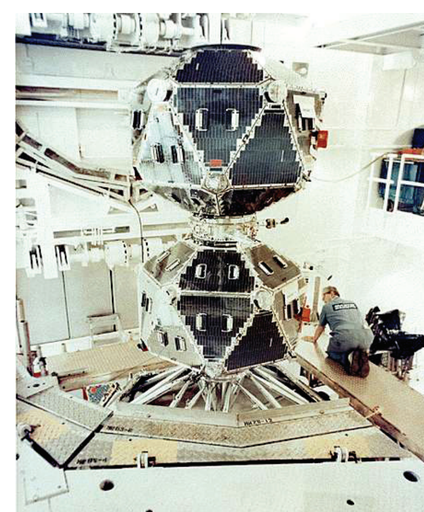
"This was one of the very first efforts ARPA took on when it was founded," notes Dr. Ralph Alewine, director of the agency's Nuclear Monitoring Research Office from 1980 to 1996, when he became deputy assistant secretary of defense for nuclear treaties. "And it was a big, big effort in the beginning, which was a time of lots of atmospheric testing. The president decided the United States needed ways to monitor these and potentially have treaties regulating it.

"In addition to research programs and technology development, DARPA was a source of technical expertise DoD used in nuclear test monitoring negotiations, starting in 1962 with the Soviet Union on banning atmospheric tests. That led to the 1963 treaty banning explosions in the atmosphere. DARPA played a key role in getting verification arrangements and what we could do and accept in the way of treaties and how to monitor them."

DARPA's first, big effort in nuclear-test detection was called Vela, which began as a small research project in 1959, but grew into one of the keystones of nuclear-test monitoring. The program had three components: Vela-Sierra, or Vela-S, to monitor nuclear explosions or radiation in space; Vela-Hotel, or Vela-H, for high-altitude atmospheric tests; and Vela-Uniform, or Vela-U, for everything underground. The first pair of satellites was launched three days after the 1963 treaty was signed.

"These Vela satellites had two kinds of sensors – optical to measure bright light from a nuclear explosion, which has a characteristic optical signal and EMP [electromagnetic pulse]," Alewine explains. "DARPA did all the original work on sensors and satellites for nuclear-test detectors, but the Air Force ran it on a day-to-day basis.

"Another kind of satellites, launched in the early 1970s, tracked radioactive debris. If you have an atmospheric explosion, the



NASA photo

debris is swept high by the wind and you can use satellites to track the radiation cloud. They were used to track Chinese nuclear tests, based on gamma ray radiation."

As the first treaty was about to go before Congress for ratification, Robert Sproull arrived as the new DARPA director (1963-1965).

"So my first problem at ARPA was helping the Joint Chiefs generate testimony leading to the confirmation of the Partial Nuclear Test-Ban Treaty," Sproull says. "The three environments – the oceans, the land, and space – were all ARPA projects of one sort or another, mostly done in the national

Above: The ratification of the Limited Nuclear Test-Ban Treaty in October 1963. President John F. Kennedy signs at the White House in the presence of Vice President Lyndon B. Johnson, Secretary of State Dean Rusk, and a group of senators and advisors. With the passage of the treaty, ARPA was charged with ensuring that the agreement could be verified. Opposite page: DARPA's Vela satellites became a crucial component of its nuclear-test-monitoring activities.

National Archives photo

labs. The Joint Chiefs wanted assurance that the ability to [detect] nuclear-test violations was there – and that was ARPA."

With a treaty on atmospheric and space tests in place, the United States and the Soviet Union began talking about the remaining area of contention – underground testing. Once again, the call to develop and validate the required technology went out to DARPA.

"That fourth environment was not part of the treaty, although during the summer of '65, all of the meetings had to do with, 'Can you make it part of the treaty?'" Sproull says. "We thought the missing ingredient was the ability to discriminate earthquakes from underground tests."

There was another factor involved in monitoring nuclear tests beyond the enforcement of treaties, however.

"If you do see something, you want to learn about it. How big is it? What's the yield? Is it a multi-stage device? What can you learn about the technology from this teleseismic signal? So, you get into diagnostic, because that's why they are doing things. It's very different if that's a brand-new, revolutionary test device or whether that's a test to see why something in their inventory doesn't work," notes former Director Steve Lukasik (1971-1975). "So it really is, when you think about it, more than the simple matter of distinguishing between explosions and earthquakes."


Dr. Ralph Alewine, director of the agency's Nuclear Monitoring Research Office from 1980-1996.

Photo courtesy of DARPA

As with most DARPA research and development, however, those efforts also led to a host of other advances far removed from the subject of nuclear weapons.

"The 1963 treaty only banned explosions in the atmosphere and space because the technology did not exist yet to detect underground tests," Alewine says. "As part of those early programs, as far as underground detection was concerned, DARPA created the first World Wide Standardized Seismograph Network (WWSSN).

"At the time, the field of seismology did not exist, so DARPA basically invented global seismology, putting out about 130 sensors around the world, all uniform, with the film created returned to the United States for scientists to use in research. One of the scientific results was the discovery of plate tectonics. Without the DARPA system, they would not have had the data needed to discover plate tectonics."

Continuing to push the technology, DARPA worked through the 1960s to make the WWSSN more digital and, in 1973, joined forces with the U.S. Geological Survey to develop and deploy a network of 13 Seismic Research Observatories that incorporated an advanced digital recording system. This global effort not only established the agency as a leader in such research, but also enhanced its ability to work with other nations and institutions in a way that had not previously been seen.

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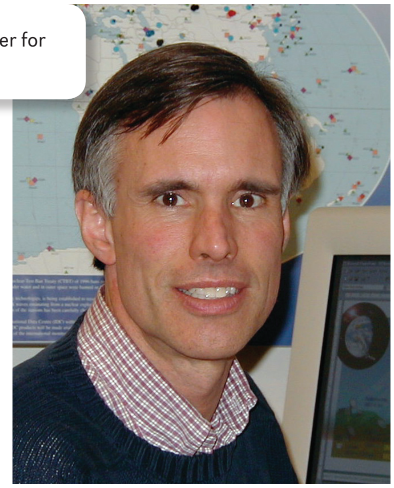
> *– Dr. Ralph Alewine, director, Nuclear Monitoring Research Office, 1980-1996*

"It's ironic that DARPA and ARPA probably were better known in the seismic-monitoring community outside the U.S. than inside," says Steve Bratt, DARPA's program manager for data processing (1993-1996) and a key player in the eventual transition of the agency's test detection efforts to an international organization. "Within the global seismological community in general and the nuclear-detection community specifically, DARPA was both a known and a trusted commodity. Putting on workshops, funding research projects in other countries – all that created a high level of trust in what DARPA was doing. I think people were largely grateful the U.S. was willing to fund so much of this research that improved global capabilities – and the U.S. benefited by getting access to both assets and people in those countries."

Underground explosion detection was one of the original examples of a "DARPA-hard" problem that required bringing together multiple disciplines, technologies, partners, and approaches.

"There were two central problems – getting sensors that could detect very small underground signals, eliminating other noise, and how to process these global sensors and all that data, looking for a needle in a haystack,"



Steve Bratt served as DARPA's program manager for data processing from 1993 to 1996.

Photo courtesy of DARPA

Alewine explains. "That led to creation of the Vela Seismological Center, which was a kind of prototype data processing system, run by the Air Force for DARPA in Alexandria, Va.

"DARPA also was a big user of computer systems, mass storage – and this program was the biggest user of that. In trying to detect these real small signals, DARPA had the Very Large Array Program. The first of these was the Large Aperture Seismic Array [LASA], which covered most of eastern Montana. There was no phone system in Montana that could support it at the time, so DARPA basically created a phone system for eastern Montana to support it."

Originally built in 1964, LASA remained in operation until 1978, during which time other arrays were placed around the world. Those included the Norwegian Seismic Array (NORSAR), a second-generation facility built in concert with the Norwegian government outside Oslo in the late 1960s that has been in operation since 1971.

"Why Norway? Because Norway could not only see Soviet explosions, it could see U.S. explosions," Lukasik explains.

But the larger the array, the more uncorrelated both the noise and signals received became.

"So we had to get smarter – and smaller – with these arrays," Alewine continues. "That evolved into regional array: two in Norway, and one each in Finland and Germany. That led to a follow-on center – the Center for Monitoring Research [CMR], in Rosslyn, Va. – based on the smaller arrays [the Vela Center was closed when CMR went online]. We created an expert system to look at the signals and correlate them. It was kind of like a neighborhood watch, looking at regional data and correlating it with neighboring regions. That was in the late '80s and early '90s and was the prototype for all kinds of later expert systems."

Bratt calls the Rosslyn Center unique in its approach to the use of rule-based systems and neural networks to create what many considered the most advanced expert system knowledge base in the world at the time.

"We were applying AI [artificial intelligence] techniques to solve real problems. The software for data collection, signal detection, locating and characterizing events [earthquakes, explosions, etc.], and the human analysis tools were all based on DARPA technology," he says.

"It was kind of revolutionary, but the idea was that expert systems could never be perfect, so they would make a first pass through all the data, then a human analyst would be presented with the data and the expert system's conclusions and make any corrections needed; those then would be used to improve the AI system over time."

DARPA also was instrumental in bringing experts from the Soviet Union, Norway, China, Japan, France, Australia, and others into an active collaboration to resolve the problems they faced.

"Another pioneering thing we did at DARPA was look at four technologies – seismic, hydroacoustic, infrasound [sensors in the atmosphere], and radionuclide [air sampling]," Bratt says. "An explosion in the ocean gives off both acoustic and seismic signals and may leak some gases or radiation into the air. We applied the processes we had developed for seismic monitoring to look at all these different tools together. And that was pretty radical."

DARPA took advantage of every new possibility – whether science, technology, or diplomacy – to expand and enhance its monitoring mission.

"Just after Nixon went to China, we had a cooperative program putting sensors in far western China, sort of for research, but really to monitor Soviet test sites," Alewine recalls. "We also used the *Glomar Explorer* [a large deep sea research ship] to drill beneath the seafloor off the Kuril Islands, just outside Soviet territory off Kamchatka, in water 5 kilometers deep. We could drill several hundred meters through the seafloor into very hard rock and put seismometers into the seabed.

"We also continued looking for techniques for monitoring from space and built an imaging gamma ray detector, the first that could take a picture of gamma rays and get a radiation image of another spacecraft. They were designed to go into space, but we used them in high-altitude balloons launched from Australia and Antarctica, and in the nosecones of U-2s to get right under the orbits of Russian nuclear-powered satellites. We ended up using them against ships; we could tell which ships were carrying nukes and exactly where all the warheads on the ship were, much to the chagrin of some U.S. Navy cruiser captains. The follow-on technology today is used for port security."

The expertise DARPA developed in its four-technology approach also found non-nuclear detection applications, such as locating tunnels North Korea was digging under the Demilitarized Zone.

Today's Internet also can trace a major part of its early development to nuclear-test detection, as one of the major early applications of what then was called ARPANET was the transmission of seismic readings from various sensor stations around the world to a central analysis center.

"We didn't really intend to wire the world together in the Internet, but that's what happened. And we wired the seismic world together," Lukasik says. "Otherwise, it used to be you would mail in your tracings every day or two and it would take three weeks before all the data came in."

Another area of test monitoring with unique problems DARPA was called upon to resolve was underwater testing, which, as had been the case before, brought different areas of DARPA expertise together with that of other parts of the government, such as the Office of Naval Research.

"There's another category called 'technology pull.' There are cases where we have problems in defense that need focused research efforts because they are full of research uncertainty. They're full of geophysics uncertainty, for example," notes former DARPA Director Robert Fossum (1977-1981). "A substantial portion of our research budget was in nuclear-monitoring research and another was in underwater sound.

"Anything that's geophysically oriented is full of geophysically generated noise and therefore requires a great deal of research to understand that noise, to understand its effect on sensors, to understand its effect on the signal source. In the case of nuclear-monitoring research, we were very concerned about foreign nuclear testing, and the problem was not did they test or not – although that was a problem – the problem was what yields were they testing."

The decades of work DARPA put into nuclear-test detection often went far beyond the typical agency role of basic research and development, but, in the end, led to a traditional DARPA outcome as negotiations began in the late 1980s on a new U.S.-Soviet treaty.

"The last thing the [Nuclear Monitoring Research] Office did was help the comprehensive test-ban negotiations, signed in 1996. We were able to write up a verification protocol and demonstrate it," Alewine says. "The center in Rosslyn was the prototype for the international data center in Vienna, Austria, as the center of the new organization created to monitor the new treaty.

"That was the culmination of the DARPA program. The office was transferred to OSD [Office of the Secretary of Defense] in 1997, which continues the effort to this day, in a more generic sense, with some of the follow-on research being done by the Air Force."

DARPA's nuclear test-detection role was pivotal in keeping the Cold War cold – the technologies and processes developed pierced veils of secrecy that could have greatly increased the dangers of distrust and misunderstanding, and allowed implementation of a series of test-ban treaties that benefited the entire world. But science, technology, expertise, and funding alone were not enough, according to Bratt.

"DARPA was a great place to work. They hired smart people, gave them a budget, and just said 'do good things,' which led to very high productivity. So the one ingredient that helped make all that progress was the DARPA spirit," he maintains. "And getting the best minds, not only in the U.S. but in the world, working toward a common goal was challenging but, in the end, worked.

"And we delivered something – this wasn't just research papers that went on the shelf, but a tangible, real system that was deployed and works. From the first deployments in the early 1960s to now, the world of people who monitor tsunamis and earthquakes and such benefited greatly from these DoD-funded projects. There were challenges along the way, but there also were an awful lot of tangible, beneficial results."

> "Project Vela provided the means for the United States to persistently detect and globally geo-locate explosions from testing nuclear weapons."
> *– Dr. Brian Pierce, deputy director, Strategic Technology Office*