nuclear weapons journal

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Kwajalein Journal ▫ Replacing S5370 ▫ HE Engineering ▫ Environmental Management System

Weapons Science and Engineering at Los Alamos National Laboratory

Point of View

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Architectures for High Performance Computing
Computer simulation of physics has been an immensely powerful tool that Los Alamos has developed and applied over the last 60 years. Although much of the historical development has stemmed from the nuclear weapons program, Los Alamos is widely known for numerical simulations in astrophysics, global climate modeling, materials science, and in more recent years, some nontraditional areas such as economic and sociological modeling.

Computers that run these simulations have evolved tremendously since the late 1940s, when the first digital computers appeared. We have progressed from the original vacuum-tube ENIAC, through the "main frames" of the sixties and seventies, to the vector supercomputers of the eighties and the parallel supercomputers of the nineties and beyond. Current machines are literally millions of times faster than the original computers and provide the "horsepower" for our numerical simulations.

This hardware evolution is, however, not the whole story. Hardware horsepower must be harnessed by software that ranges from the "codes" that directly represent the physics through an entire software "stack" that drives the hardware. Over time, at least as much progress in all levels of this software stack has been made as there has been in the more visible evolution of hardware. The interconnected developments in this technology stack help us to understand the role that Los Alamos has played in the international developments in high performance computing architectures.

What do the codes need?

Ideally, the hardware architecture of a high performance computer should reflect the needs of the computer codes that run upon it; however, the numerical representation of physics has evolved in parallel with the hardware so that the interplay of requirements has flowed from software to hardware and back, i.e., in a "technology stack" with codes at the top that communicate through a large body of software with hardware at the bottom.

Los Alamos has been at the forefront of international developments for the past 60 years

A large subset of codes starts from the "conservation laws" of physics, mathematical formulations of common physics observations such as "matter and energy are neither created nor destroyed" and "momentum is conserved through Newton's law." These statements are not entirely correct when one speaks of the nuclear processes of astrophysics or nuclear weapons, but the principles remain the same. We must account for all processes that lead to changes in a quantity of interest, such as mass, momentum, and energy. Development of the conservation laws applied to any area of physics can be found in elementary textbooks, but they all lead to coupled sets of partial differential and algebraic equations that must be presented to the computer to solve.

Approximations of the equations are forced on us because we cannot represent the continuous solution to the equations. Mathematically, that would demand an infinite amount of information. Currently, no computer can hold this information. We must choose a representative sprinkling of locations in space and time and seek the numerical solution to the equations only at these discrete points. This sprinkling of points is known as a "grid" or a "mesh," as shown on page 16.

Continued on page 16

Journal of a Flight Mission

In September 2003, two Los Alamos weapon program managers flew to the south Pacific to participate in a flight test of the W78/Mk12A weapon system. We asked Zeke Aragon to keep a journal of this flight test; here, he describes his experiences at Kwajalein and LANL's final preparations and postlaunch activities to acquire and analyze data for mission GT-181GM. Photos are by Patrice Stevens and Zeke Aragon.

Boy, this is a long way from home!

Thursday, 4 September 2003

Patrice Stevens, LANL W76 Program Manager, accompanied me on this mission to learn how the Air Force conducts flights and to see if comparative data can or should be obtained for the W76. Both the W76 and the W78 warheads were designed and developed in the mid- to late-1970s.

The only way to Kwajalein from the mainland is through Honolulu, the first leg of a two-day trip. Today, we departed Albuquerque at 8:15 A.M., and following a stopover and plane change in Denver, we arrived in Honolulu at 3:15 P.M. The most uncomfortable portion of this part of the trip is the 7-hour flight from Denver to Honolulu. Tonight, we'll be at the Hilton on Waikiki Beach. Tomorrow holds a 7 A.M. departure time for day number two–Honolulu to Majuro, the capital of the Republic of the Marshall Islands (RMI), and then on to Kwajalein.

Friday, 5 September/Saturday, 6 September 2003

We woke at 4 A.M. to catch a 7 A.M. flight to Kwajalein via Majuro. There's only one flight a day to Kwajalein, so you don't want to miss it. At check-in at the Honolulu airport, the flight gate attendant requests a copy of the pre-authorized entry authorization (EA) form prior to seat assignment—no form, no seat! Crossing the International Date Line, we arrive in Kwajalein at 11:45 A.M. on Saturday, 6 September (18 hours ahead of MDT); base security is the next stop. Trained dogs check our bags for explosives, fruits, and drugs. Once the EA forms are turned over and verified, we're issued an island picture badge. Then, we check in at the Kwajalein Lodge for accommodations at a dorm-type room. Private and commercial vehicles are not allowed on the island, so transportation choices are a golf cart,

The W78/Mk12A Minute Man (MM) III weapon program conducts special flight tests that require the participation of the Intercontinental Ballistic Missile (ICBM) community: HQ Air Force Space Command (AFSPC) at Peterson AFB; Vandenberg AFB (VAFB) where the missile is launched; the ICBM System Program Office (SPO) at Hill AFB; missile support; civilian contractors to the Air Force; and NNSA and three national laboratories—Sandia, Livermore, and Los Alamos. This community conducts annual surveillance flight missions for the W78/Mk12A reentry vehicle (RV), the W87/Mk21 RV/Peacekeeper weapon system, and the W62/Mk12 RV/MM III system. Most of these flight missions use instrumented joint test assemblies (JTAs), but every other year, the W78/Mk12A weapon system flies a noninstrumented JTA that uses nonnuclear surrogates. The September 2003 mission for this system consisted of an instrumented JTA6 and a noninstrumented JTA5 test warheads.

Flight missions are conducted at the Kwajalein Test Site, a US Army facility that recently was renamed the Ronald Reagan Ballistic Missile Defense Test Site (RTS). As with other tests, this mission impacted near the Kwajalein Atoll.

for a daily price of $30, or a bicycle for $5 per day. We arranged for a golf cart. Lunch was next at the dorm snack bar.

Because of Kwajalein's proximity to the International Date Line, their workweek is Tuesday through Saturday to better match the US mainland. With this being Saturday, the next thing is to obtain an additional security badge that allows entry to the mission control center, a classified area. At 1:30 P.M., a briefing for me by LLNL staff was followed by an RV recovery meeting with the Army recovery crew. We reviewed an initial concern: if the JTA5 impacts Illeginni Island instead of the ocean, recovery of all classified and/or hazardous components is required.
At 4 P.M., we met with Maj. Kelvin Townsend, AFSPC, to bring him up to date on our activities. Another meeting with Peter Terrill, LLNL team leader, to plan the remainder of the activities leading to launch day, followed dinner. These include deploying the flotilla, optics setups, and data-receiver antenna location setup. After this meeting, we called it a day.
Kwajalein temperature 92°F, 96% humidity

Our LCU transport, the Great Bridge


Patrice Stevens and camera

Sunday, 7 September 2003
Woke at 3:30 A.M. (biological clock still set to MDT). I tried connecting to the LANL off-site computer server. After several tries, I decided to quit and have breakfast at the Café Pacific cafeteria and then attend church at the island chapel. Since Sunday and Monday are the Kwajalein weekend, I spent the rest of the day touring the island to renew old acquaintances. Was invited to a birthday party that evening.

Kwajalein temperature 88°F, 80% humidity, a little sticky with no wind

Monday, 8 September 2003
My biological clock is still off, and I'm up at 4 A.M. Tried again to access e-mail. Called computer support at home, but he can't help until Monday morning (Los Alamos time) because no one is available at CCN.

Met LLNL staff at the raft flotilla garage for final performance checks at 9 A.M. At 2 P.M., a data-connection line check was performed between mission control center and Illeginni Island. After 4 hours of tests, the problem was traced to a signal conditioner on Illeginni. Tomorrow morning, a crew will helicopter there to replace a faulty computer card.

Shopped at Macy's department store for T-shirts and hats to take home to the family. This is the only place to obtain dry goods on the island; it's the size of the lower floor of CB Fox (the local Los Alamos department store) and offers items ranging from clothes to furniture, to electronics, to home decor. A limited selection, as one might guess, but you can special order items that usually take two to three months to receive. This delay is because the store is restocked only once a month, when an ocean-going barge arrives from Honolulu. This is also true for the grocery store, called "Surfway"! However, breads and pastries are made locally, and perishables arrive by cargo plane every other day, except weekends.

Tonight, the entire crew got together for a pre-mission dinner, a tradition that LLNL started back in the W87 life extension program (LEP) development days. After today, there'll be little chance for socializing until the mission and data analysis are complete. Dinner was a Caesar salad, homemade lasagna with garlic Italian bread, and chocolate cake for dessert. Chef Peter Terrill did a great job. Another day ends.
Kwajalein temperature 93°F, 88% humidity

Patrice and Zeke with detector and camera rafts

Tuesday, 9 September 2003

Woke at 4:15 A.M. again and called Los Alamos to check on my LANL server connection—they're working on the problem. Finally received a call to change a setting on my laptop...problem fixed as I received 83 messages!

After breakfast, I attended an 8 A.M. mission-day weather forecast. A chance of showers is forecast for morning and midday. The missile launch window opens at 11:31 P.M. local time, and we hope that the chance for showers will be minimal by impact time. A cloudless or partly cloudy sky makes a spectacular RV reentry show. Met with Charlie Kang, the ICBM missile test point of contact (POC) at Kwajalein, to make sure that both Patrice and I will have access to the KMCC (Kwajalein Missile Control Center) at mission time. Went back to my room to work some e-mail issues. After lunch, met with Kathy Wade, LLNL camera control, to verify that the faulty computer card problem was fixed. All is well.


Lowering raft into water

Lt. Col. Daugherty, Kwajalein's Range Commander, called a meeting at 3 P.M. for LLNL, LANL, AFSPC, and her range safety staff for a briefing on the ICBM environmental assessment status. She is new on the island and wanted to be brought up to speed on this issue. Maj. Kelvin Townsend, AFSPC, informed her the environmental assessment would be rewritten soon to include the W87/Mk21 aboard an MM III.
LLNL and LANL will be required to supply hazardous material information for the environmental assessment, and AFSPC and the State Department will be POCs for the RMI. This information is available at AFSPC and should not be a major issue for LLNL or LANL. A minor update will be needed for the new W78 JTA6 flight test unit.

At this meeting, I was told that the US/RMI compact renewal, which details US usage of the Kwajalein Atoll, has been signed but must be ratified by both governments before it's in force. Ratification should be accomplished by the end of the month. If all goes well, we will be allowed to continue our testing program. Another political issue looming over our range usage is the RMI presidential election on November 14th.
The incumbent favors US connections, his opponent does not. Stay tuned...

Dinner was a quick trip to TenTen, the local seven-to-eleven store, for a frozen dinner. Too tired to go to the cafeteria, and tomorrow's activities mean
a 6 A.M. departure of the *Great Bridge*, the LCU (landing craft utility) ship that will transport the raft flotilla to the southeast side of Illeginni Island. I've

arranged for Patrice and me to be part of the ship's crew.

Kwajalein temperature 92 °F, 96% humidity; calm winds (ocean winds make this bearable, without them...o'boy!)

Wednesday, 10 September 2003, Mission Day

Alarm rang at 4:45 A.M., with enough time to get ready for a day at sea. Today consisted of the three-hour cruise to Illeginni aboard the *Great Bridge*. With its main deck fully loaded with rafts and supporting equipment, the LCU is a sight to behold.

As with other ships I've been on, we were served a great breakfast—the kind that my mom used to say "will put meat on your bones." Our captain, Nate Jackson, is a smooth sailor and helmsmen, artfully maneuvering the *Great Bridge* out of the Kwajalein dock and into a tight, shallow docking area at Illeginni. Upon arrival, the LLNL crew commenced final checks of all optics installations and final communication checks with the rafts. Patrice and I toured Illeginni. The temperature must have been in the 90s with humidity in the same vicinity and no wind—an uncomfortable day ahead. Once the checks were completed, all activity ceased until mission control OK'd deployment of the rafts. Lunchtime! Again, the ship's cook is a master. We had our choice of spaghetti with meat sauce, hamburgers, grilled chicken or hot dogs, with a vegetable salad or fruit, and ice cream for dessert.

Zodiac boat securing rafts

Word came at 1:15 P.M. to commence raft activities. A crane lowered the rafts overboard, where Zodiac rubber boats pulled two rafts at a time to their station. Ten neutron detector rafts and two camera rafts were deployed; deployment was accomplished by 3:15 P.M. This raft array will gather data to determine RV targeting accuracy and warhead performance.

Typical launch from VAFB

After a quick dinner aboard ship, we caught our helicopter back to Kwajalein. The 20-minute flight returned us to our dorm rooms with enough time for a quick shower and a change of clothes, something one learns to do often to be as comfortable as possible. After resting for a bit and trying to check e-mail, it's time to head to the KMCC.

The KMCC is one of two mission control facilities for ICBM flights, with the other at VAFB. With VAFB and RTS having test directors, a final "go" for any mission rests on the two individuals agreeing that the launch point and the impact point meet certain criteria. KMCC is your typical control center, with numerous monitors and screens in a darkened room, with visitors, including Patrice and me, in the VIP observation deck. The launch is visible via a closed-circuit TV.

GT-181GM lifted off on time, at 11:31 P.M. Kwajalein time (4:31 A.M. PDT). This flight consisted of three RVs aboard an MM III missile; one DoD bird (or RV) and two DOE test units (one JTA5 Hi-Fi unit and the developmental flight test unit of the new JTA6 design). Impact of all three birds occurred approximately 28 minutes later.

With approximately 5 minutes of flight time left, most individuals in the VIP observation deck ran to the edge of the Kwajalein lagoon to see the RVs streak across the sky, normally a sight to behold. Tonight, the RVs repeatedly entered and came out of the cloud cover—still a great sight.

Spent the rest of the night reviewing data and collectively evaluating flight test results. Some radar data won't be available for about three weeks, as flight trajectory plots need to be compared with the optics for the final flight test report. It's now 5:09 A.M., Kwajalein time, and tomorrow will be another long day, reviewing optics films that will be brought back by helicopter first thing in the morning.
Kwajalein hot and sticky, but didn't really check temperature, too many things going on.

Thursday, 11 September 2003

After a little sleep, a quick shower, and a muffin and coffee at the bakery shop, off to the Photo Lab. First items out are the 35-mm still shots from the land-based cameras, which showed the two DOE birds streaking across the sky, then high-speed videos, and finally the all-important high-speed 70-mm film.

Meantime, the LLNL crew and Army divers retrieve the raft flotilla to obtain the data, which arrived around midday. Reviewing data took most of the day—tomorrow as well, most likely. Finally found time for dinner around 6:30 P.M. and some relaxation.
Kwajalein temperature 88 °F, 92% humidity

Friday, 12 September 2003

After breakfast, we continued reviewing and comparing data, principally the flotilla data and the radar images, trying to establish the actual impact point and other information that is part of the Air Force's mission success criteria. After all available radar data have been reviewed for completeness, further analysis will have to wait until the raw data are transported to Lincoln Laboratory—part of MIT—for format reprocessing, and then forwarded to Xontech for final processing and assessment. The final process is part science and part art. I've been involved with Xontech for almost 10 years, and I still don't understand how Doppler radar data reveals information critical to understanding what's going on exo-atmospherically during a flight of a nonrigid body. LLNL will take the flotilla data back to California, generate a mission report, and submit it to me by the end of October.

After our lunch, it's time to get ready to leave Kwajalein—do laundry and make final purchases at Macy's.
Kwajalein temperature 92 °F, 87% humidity

Saturday, 13 September 2003

Now we start our long trip home, from Kwajalein to Majaro, to Honolulu (first leg); then a day in Honolulu to ease the impact on our biological clocks and then on to Albuquerque on Sunday. This is always the curious part of the trip: we left Kwajalein at 9:30 A.M. Saturday and arrived in Honolulu at 6:30 P.M. on Friday, 12 September. The travel office initially had trouble understanding why I needed a hotel reservation in Honolulu on Friday when I leave Kwajalein on Saturday. Checked into the Hilton Waikiki Beach Hotel and had a quick meal downstairs, too tired to go elsewhere for dinner, then off to bed.
Honolulu temperature 88 °F, 66% humidity, great!!

Saturday, 13 September 2003 (for the second time!)

Met Patrice for breakfast and made plans to visit the Arizona Memorial at Pearl Harbor, a solemn place, then to Hilo Hattie's where tourists buy Hawaiian stuff, and finally the beach. Called it a day at early evening, still fighting the biological clock.
Honolulu temperature 85 °F, 72% humidity, still great!!

Sunday, 14 September 2003

Checked out at 6:30 A.M., departed for airport—the 9 A.M. flight to Denver via San Francisco and then Albuquerque was waiting for us. Another long day. Finally arrived at home on Monday, 14 September 2003, 12:45 A.M.

Postscript

This trip has pluses and major minuses but the programmatic value far outweighs the effort required to plan, conduct, collect, and analyze all the data associated with such a mission. Los Alamos and the crews associated with this type of mission will continue this work because of the value added to determining the health of the W78/Mk12A weapon system—it continues in service far longer than its

Developing Replacement Hydrogen-Blown, Silicone Foam Materials

S5370 is a hydrogen-blown, room temperature vulcanized (RTV) silicone foam rubber that was produced by the Dow-Corning Corporation until 1995. A replacement for S5370 is required for every system lifetime extension program (LEP) because it is a critical material in nuclear weapons components that are part of the enduring stockpile.

The Materials Team of ESA-WMM has been tasked with developing a replacement for S5370. The team worked with researchers at the Honeywell Kansas City Plant (KCP) on the material development and coined the replacement for S5370 “LK3626” to indicate the combined development efforts of both LANL and KCP scientists and researchers.

LANL scientists recognized that a replacement material should be as similar as possible to the original S5370. Essentially, a so-called “drop-in” replacement was needed that

- had similar processing characteristics, so that the new material can be used to produce thin, contoured parts for nuclear weapons;
- exhibited similar mechanical and long-term properties, such as load and load-retention characteristics, at comparable densities; and
- was chemically very similar to S5370, to ensure chemical and physical compatibility.

KCP research indicated that a replacement formulation for S5370 should consist of a simple physical mixture of the following: three molecular weights of polydimethysiloxane (PDMS), a blowing agent, two multifunctional cross-linking agents, and diatomaceous earth filler material (Figure 1).
This type of straightforward mixing has several advantages:

- in-house evaluation of all materials,
- in-depth familiarity with all ingredient and product properties,
- the ability to set specification limits for ingredient lot quality and product quality control, and
- the elimination of potential supply-chain issues.

Foam samples were produced by combining the

We successfully developed a replacement for S5370, a critical material for every LEP, that is no longer produced commercially

resultant liquid suspension with a tin-based catalyst, mixing vigorously, and pouring the mixture into a mold. The chemical reactions of this mix are very fast, occur simultaneously, and are complete in approximately 15 minutes. These reactions are catalyzed by tin-octoate and trace water. First, hydroxide-terminated PDMS chains of the three PDMS molecular weights react with polymethylhydrosiloxane (PMHS). Hydrogen released during this reaction acts as a blowing agent for the foam. Simultaneously, diphenylmethylsilanol (DPMS) reacts with PMHS, which adds bulky phenyl groups to the network and releases a significant amount

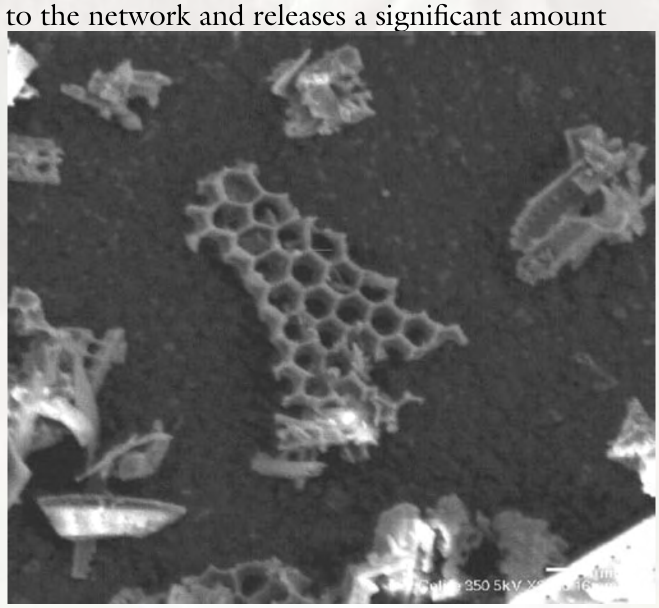

Figure 1. Scanning electron microscope image of diatomaceous earth filler used in S5370 and its replacement, LK3626. Microscopic diatoms are mined from earth deposits. Note the anisotropic shape of some filler particles.

of hydrogen, based on stoichiometry. The bulkiness of the pendant phenyl groups lowers the foam service temperature by preventing crystallization in the network PDMS chains. This allows the foam to maintain flexibility even at very low temperatures, as is characteristic of silicone materials. Finally, a tetra-functional cross-linker, tetrapropoxyorthosilicate (TPS), reacts with silanol groups to continue the formation of the foam network. Propanol released during this reaction, and the residual catalyst, are eliminated through a postcure sequence at elevated temperature. The rubber network can form through any of these reactions. Contact with the mold gives the foam a surface skin; the molded material is soft and flexible. The diatomaceous earth filler gives the foam its tan color.

The LANL Materials Team optimized the relative amounts of the three molecular weights of PDMS ingredients, based on established quantitative measures of acceptability—using material characterizations such as application time or "pot life," free-rise density, and compression set—and compared their formulations to samples of the original S5370.

Most important to formulation optimization, however, were the load-deflection properties of the LK3626 foam in uniaxial compression. Figure 2a shows a load (stress)-deflection curve representative of LK3626; Figure 2b shows a load-deflection curve of S5370. Due to the Mullins effect, all foam samples were preconditioned by cycling the material through the strain range three times. Critical parameters were collected during the fourth cycle, including load at 20%, 30%, and 40% deflection (Figure 3).

During its research, the Materials Team generated variously successful formulations. Figure 3 shows that several of these formulations exhibited loads that unfortunately were not similar to S5370 (such as H48L24 and H69L3). For example, an excess (or absence, in the case of formulation H72L0) of one PDMS molecular weight resulted in below-standard performance. After initial optimization tests, a second optimization experiment was conducted to study ingredient and resin shelf-life issues, allow more ingredient characterization and specification development, and provide more scrutiny of the most promising formulations. The team conducted additional tests, including residuals extraction, and addressed issues related to side reactions in the resin, moisture analysis of the diatomaceous earth filler, and spatial distribution of density in weapons components fabricated from the various formulations. LK3626 represents the optimal formulation based on the listed variables and responses.

The team expresses appreciation to G. Keith Baker, formerly of the Bendix (now Honeywell) Kansas City Plant, who originally de-engineered S5370.

Tim Weeks, ESA-WR, measured the load-deflection properties of the LK3626 foam in uniaxial compression.

More and more replacement materials will be needed over time, as nuclear weapons components that are slated for replacement cannot be manufactured due to the lack of available materials or to environment, safety, and health concerns. With S5370 and other materials no longer on the market, producing a material that is a seamless "drop-in" replacement is critical for LEP activities. Lessons learned during the LK3626 development project will aid these activities. One major factor in the future development of replacement materials, which the LANL ESA-WMM Materials Team demonstrated and addressed, is the need to control the mechanical properties of the material by fine-tuning the nature of the ingredients that make up the material—a critical part of the structure-property toolkit that the team is striving to build. In the case of LK3626, the team succeeded by varying the ratio of PDMS molecular weights to achieve a replacement material as similar as possible to the original.

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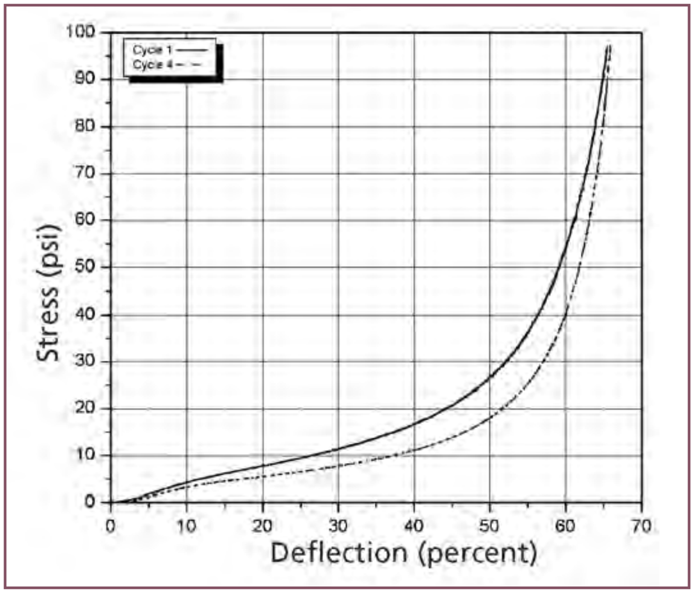

Figure 2(a)

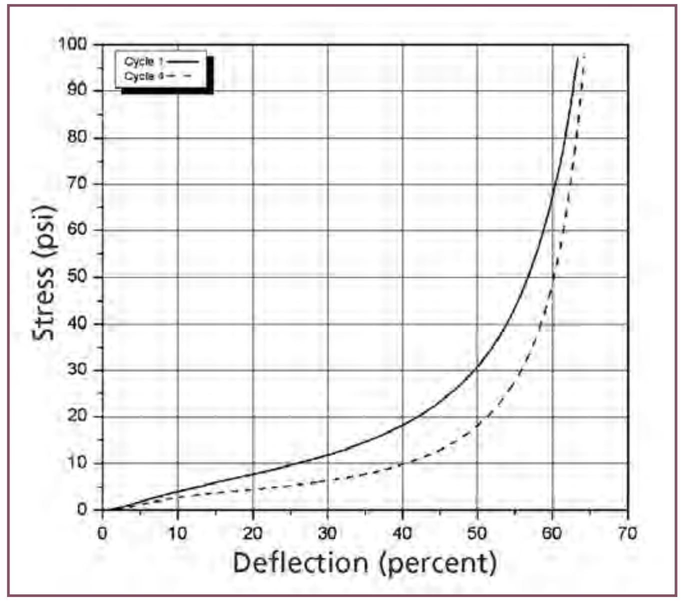

Figure 2(b)

Figure 2. (a) Stress-deflection curves from first and fourth strain cycles of a preliminary sample of S5370 replacement material, H54L18. The Mullins effect is visible as the hysteresis in stress from the first to fourth cycles. (b) Stress-deflection from the first and fourth strain cycles from a sample of S5370. Note the similarities in stress profiles between both stress-deflection figures.

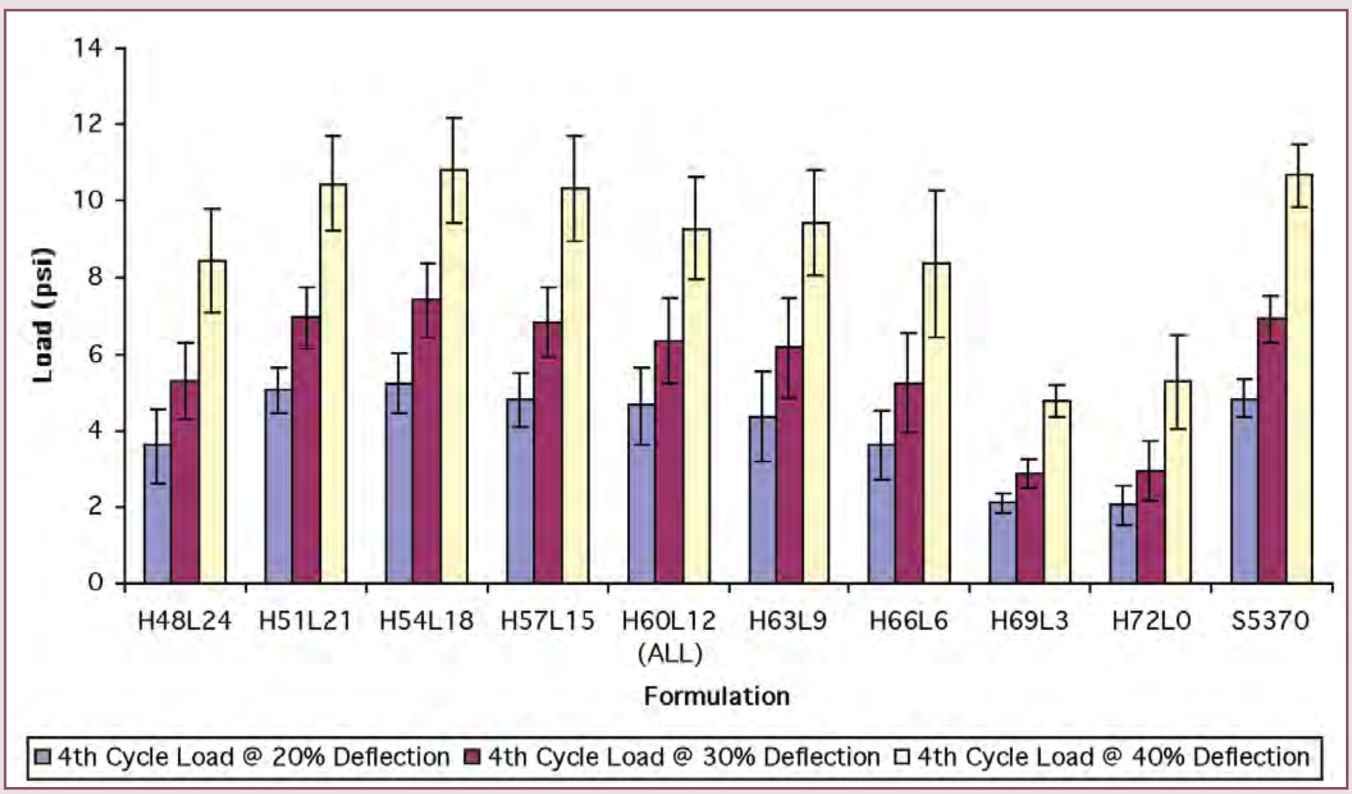

Figure 3. Fourth-cycle load values at 20%, 30%, and 40% deflection for each of the nine LANL formulations and for S5370.

High Explosive Engineering Project

Modernizing our Manufacturing Base

The high explosive (HE) system in a nuclear warhead is the principal driver of the total warhead system. A thorough understanding of HE behavior, from the molecular to the continuum level, is critical to assessing the effects of stockpile aging on our weapons and their response in various stockpile-to-target sequence (STS) environments and accident scenarios.

Because of the moratorium on nuclear testing, we must utilize efficient alternative methods of extensively testing explosives systems to assess and predict their performance, safety, and reliability as they age. Therefore, the Laboratory must have the capability to fabricate, assemble, and test assemblies of all types: physics, hydrodynamic, subcritical, flight test, surety, and environmental. (Environmental assemblies are instrumented and tested to simulate various scenarios of a weapon's STS.) Providing a modern manufacturing infrastructure that delivers HE components to the experimentalist—at reasonable cost with on-time deliveries—is essential to our stockpile stewardship mission.

Maintaining the Laboratory's HE processing infrastructure requires a multidisciplinary approach that applies modern manufacturing techniques within a challenging safety envelope. To this end, the HE Engineering Project focuses on significantly modernizing and improving our large-scale HE operations that range from material receipt to machined HE components acceptable for assembly or direct use in an experimental application.

Although the current HE infrastructure at the Laboratory is undergoing significant change, it still reflects the evolution of the nuclear weapons program over the past five decades. The current dispersal of large manufacturing facilities over a large area may have been appropriate in the past, but it is no longer cost-effective—for today and for the future. These 1950s-vintage facilities are approaching the end of their useful lives and will be decommissioned and demolished, converted to higher-use functions, or consolidated. Maintenance costs for these aged facilities are high, and the frequent occurrences of unexpected "emergency repairs" to address structural or safety-related deficiencies are costly and are disruptive to programmatic work.

During the past decade, ESA-WMM has made significant progress toward modernizing our LANL HE manufacturing base and integrating proven technology into its core capabilities. Our theme for modernization continues to be modernizing our capabilities while significantly reducing floor space. This theme also supports the ESA Division strategic vision of having a more lean, responsive, cost-effective HE Plant. We eliminated large, obsolete facilities and either converted them to higher-use operations or decommissioned and demolished them. The following are some of the HE Engineering Project's major accomplishments.

modernizing our capabilities while significantly reducing floor space

- Inert powder production of stimulant HE materials was downsized from a dedicated 13,000-square-foot facility at Technical Area 16, Building 300 (TA-16-300) into two 400-square-foot operating bays at building TA-16-260. In addition to achieving a significant reduction in space, we increased operations capability by replacing obsolete pneumatics with electronic controls, modularizing operations with stand-alone tempered water systems, and reducing worker exposure to dust and solvents through an improved ventilation and exhaust system.
- Mechanical inspection was reduced from a dedicated 6,000-square-foot facility (TA-16-280) into two 400-square-foot bays at TA-16-260. TA-16-280 was then modified to house the Packaging and Transportation operations relocated from TA-16-360.
- Powder inspection of raw, bulk materials entering S-Site's HE operations was relocated from TA-16-380, and the process was engineered to fit into one bay at TA-16-430—a 6,000-square

foot-reduction.

- X-ray examinations of pressed HE billets were downsized from a seven-facility complex into two bays at TA-16-260.
- TA-16-260 is currently undergoing reconfiguration to house HE pressing operations. This will allow us to vacate TA-16-430 and move our entire pressing operations to four bays at TA-16-260, a 14,000-square-foot reduction.
- The TA-16-Burning Grounds has been modernized with an HE Waste Water Treatment Facility and an environmentally improved thermal decomposition system that meets or exceeds National Environmental Policy Act criteria. Potentially contaminated wastewater released to the environment has been reduced from 22 National Pollutant Discharge Elimination System outfalls to 2, and the wastewater from our HE operations has been reduced from 12,000,000 to 135,000 gallons annually.
- An HE machining "Over-Test" facility is being constructed at the Burning Grounds to support the safe operation certifications required for newly developed energetics.

At the process level, significant capability and technology changes are ongoing.

- Three Computerized Numerical Control machine controls have been retrofitted.
- A "Quick-Line" has been implemented to respond rapidly to experimentalists' HE component requests. This capability consists of three conventional machine tools (lathe, mill, and saw). It replaces the small HE machine capability at TA-9-48 and consolidates all Laboratory HE component fabrication to TA-16-260.
- The x-ray function for inspecting HE billets to ensure that no foreign objects or large cracks exist in billets released for machining has been upgraded with a real-time radiography capability.
- Mechanical inspection has been upgraded with a Computerized Measuring Machine.
- A new isostatic press has been purchased for pressing operations relocated from TA-16-430 to TA-16-260. The new press will be installed during the construction reconfiguration of TA-16-260 scheduled for completion in FY05.
- Closed-loop coolant recirculation systems have completely eliminated the release of potentially contaminated HE wastewater to the environment at TA-16-260.

Prediction of future HE program assignments to Los Alamos is uncertain. Yet, within this arena of uncertainty, the capabilities of the HE infrastructure must be structured flexibly and robustly. We are ready to respond—and respond successfully—to any mission demand.

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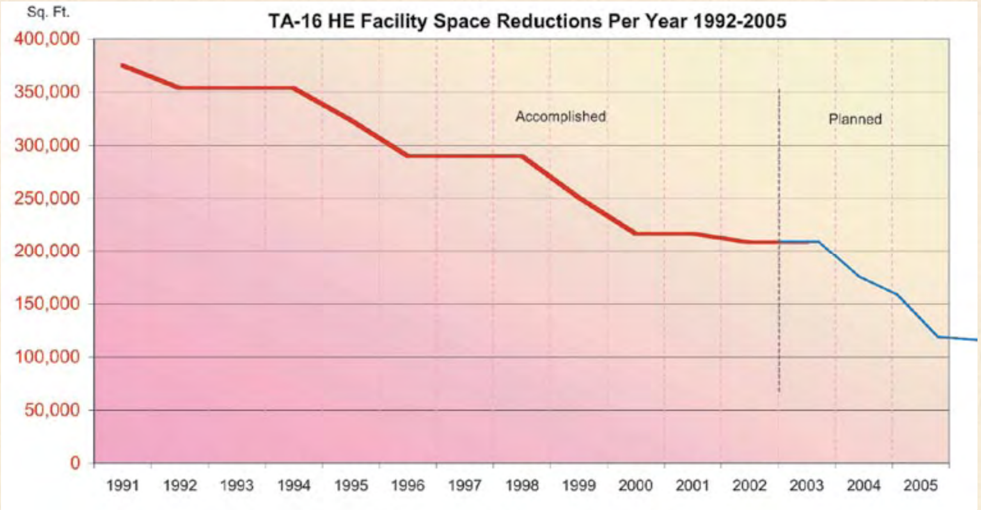

This chart graphically displays the continuing efforts of the HE Engineering Project to implement change where it makes sense and to modernize operations during the reconfiguration process. It shows the significant reductions in HE Plant square footage that were accomplished at S-Site since 1991 while maintaining and improving the Laboratory's HE infrastructure capabilities.

Environmental Management System—
A Business Imperative

Past insensitivities to environmental issues during Laboratory operations have resulted in an expensive legacy of environment, health, and safety problems and public and regulator distrust. In accordance with DOE Order 450.1, the Laboratory is developing an environmental management system to identify, reduce, or prevent the environmental impact of Laboratory operations and to rebuild public and regulator confidence.

Los Alamos National Laboratory plays a critical role in protecting national security, both in the nuclear arena and as a key provider of science and technology. But failure to proactively address environmental issues could threaten the Laboratory's contribution to national security, energy independence, and science and technology.

Unfortunately, past insensitivities to environmental issues during Laboratory operations have resulted in an expensive legacy of environment, health, and safety problems and public and regulator distrust. Therefore, in accordance with DOE Order 450.1, the Laboratory is developing an environmental management system (EMS) to reduce or prevent the environmental impact of Laboratory operations and to rebuild public and regulator confidence. Following the example of thousands of private sector companies and hundreds of government facilities that have voluntarily—and successfully—adopted an EMS, the Laboratory is taking steps to integrate environmental issues into its dual missions of nuclear stockpile stewardship and scientific research. Governmental and private sector organizations have implemented EMSs for straightforward business reasons: productivity, efficiency, cost-reduction, and return-on-investment. At the Laboratory, four business imperatives define the need for an EMS:

1. **Mission vulnerability.** Critical national security and science missions must not be vulnerable to unanticipated environmental events, such as spills.

2. **Worker health, safety, and productivity.** Proactive reduction of exposure to environmental hazards will reduce the potential for accidents and injuries.

3. **Cost management.** Environmentally responsible planning for mission and research activities will encompass the life-cycle of a project, thereby eliminating unexpected funding requirements for cleanup and potential work stoppages.

At its core, an EMS is an effective method for assessing mission activities, determining the environmental impacts of those activities, prioritizing improvements, and measuring results.

4. **Public acceptance.** Public and regulator acceptance and approval of NNSA facilities depend not only on compliance with environmental regulations but also on measurable and accountable environmental stewardship.

Mission Vulnerability

Previous environmental problems at facilities such as Rocky Flats and the High Flux Beam Facility at Brookhaven National Laboratory have decreased public acceptance of new DOE facilities. Environmental performance is a leading factor in public opposition to new DOE/NNSA facilities such as the Modern Pit Facility and new biosafety laboratories for chemical/biological counter-terrorism research here at the Laboratory. The new EMS will ensure that the design and operations of new facilities avoid the undesirable environmental and economic consequences of previous operational decisions, so as to prevent such situations during future operations.

Worker Health, Safety, and Productivity

An EMS will integrate the environment into the safety and health requirements of the Laboratory's mission: a "green" workplace will reduce the range of potentially hazardous processes associated with DOE/NNSA missions, both nuclear and nonnuclear. It is possible that a new generation of scientists, who are increasingly aware of environmental issues, also would be encouraged to come to a more environmentally friendly Laboratory. Reassessing processes and innovating changes through an EMS can make dramatic improvements in productivity, efficiency, and financial return while decreasing pollution and liability and their associated costs.

Cost Management

The successful use of EMSs in the private sector demonstrates the connections between process efficiency, environmental protection, and financial performance. A successful EMS incorporates not only the obvious costs of doing business but also the sometimes invisible costs of working in an environmentally responsible manner. For example,

- the use of highly toxic chemicals requires personal protective equipment and significantly greater planning, to avoid potential injury and cleanup costs.
- planning to minimize the amount of nuclear materials lost in waste products will reduce security, transportation, disposal, and environmental cleanup costs, as well as the costs of medical treatment for injured workers.
- an incident in one laboratory or technical process may cripple unrelated activities in the same facility or other facilities, thereby reducing time and funding that could have been applied to achieving the Laboratory's mission.
- waste management and accident reporting take a significant amount of time by front-line researchers.
- inadequate identification of environmental issues can result in inaccurate budget projections. Waste management and facility decommissioning costs usually are not factored into programmatic budgets, which leads to budget crises and diversion of current-year mission funding to address unexpected problems.

Implementing an EMS will ensure these costs are included in planning for important Laboratory missions, reducing the invisible costs that can impair productivity.

Public Acceptance

As technology increases our ability to detect smaller and smaller amounts of contaminants in the environment and as public participation in environmental decision-making increases, the Laboratory's operational processes must include ways to cope with sophisticated environmental issues. Environmental concerns have led directly to operational delays when DOE/NNSA faced public objections or litigation. Environmental laws and regulations are intended to provide the public with the power to enforce environmental standards and determine which organizations and activities should be challenged. The Laboratory's EMS will be designed to provide a proactive interface with the regulatory community, preventing many if not most environmental snafus.

EMS Development

You'll hear more about the Laboratory's EMS in coming months. DOE expects a fully certifiable EMS to be implemented by December 2005. While this effort will require significant involvement from workers, supervisors, and managers, the process need not be complicated. At its core, an EMS is an effective method for assessing mission activities, determining the environmental impacts of those activities, prioritizing improvements, and measuring results. Many EMS-like performance measures, quality assurance, and data reporting tools are already in place at the Laboratory. Divisions such as NMT, RRES, ESA, DX, LANSCE, and FWO are already conducting such assessments under the New Mexico Green Zia quality improvement program.

Unfortunately, an EMS is not a magic bullet that can be applied once for immediate improvement. A good EMS provides a system for continuous quality improvement and depends on the ongoing engagement of all process owners. The Laboratory will use this tool to integrate environmental requirements with the Laboratory mission; the Laboratory, the public, and the environment will all benefit from this environmentally responsible way of doing business.

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EMS FAQs

Q. What is an EMS?
A. An organized way to reach defined environmental objectives, incorporating environmental responsibility into all aspects of an organization's work.

Q. What is the most common EMS model/prototype?
A. ISO 14001 is the standard most commonly followed.

Q. What is ISO 14001?
A. The International Organization for Standardization (ISO) in Geneva Switzerland. ISO 14001 outlines key requirements that companies or organizations should comply with in order to operate in an environmentally responsible manner. It applies to the environmental aspects of an organization's operations over which the organization has control and that it can be expected to influence.

Q. What is a certifiable EMS?
A. After an EMS is implemented, it is evaluated by an independent auditor who then certifies that the system is functioning correctly. The Laboratory EMS should be ready for such "certification" in 2005.

Q. Who is affected by an EMS?
A. Everyone. Environmentally responsible planning for mission and research activities encompasses the entire scope of an activity—from procurement to closure.

Q. Who benefits from a Laboratory-wide EMS?
A. The Laboratory, the public, and the environment will all benefit from this integration of environmental awareness into business and scientific procedures.

A Safety Culture: How do we get there?

How do you change the personal safety culture of such a large, diverse working group as Los Alamos National Laboratory? That's a very difficult and complex task.

To develop a safety culture here, we need to change the values, standards, and norms of acceptable behavior for all the people that work here, whether undergraduate students, visitors, post-docs, contractors, technicians, UC employees, staff members, managers, researchers, or fellows. What an unbelievable and daunting challenge!

A culture of safety would need to be inherent in the thoughts of every individual at every level of the Laboratory. All safety considerations are affected by common beliefs, attitudes, behaviors, and cultural differences and are linked by a shared set of values and standards. If this is our goal, what will it take to get there?

Individuals must commit to safety in the workplace and act on that commitment. One team in ESA-AET is taking their safety culture seriously. They have reserved time at their Nested Safety and Security Committee meetings for a guest scientist, Dr. Lee Brown, to address the team on his safety-related experiences (Brown is a former Laboratory employee and teacher of risk analysis as it relates to safety). With Brown's help, each member of the team adopted a challenging set of personal safety rules:

- I will value safety as a positive, integral part of my everyday activities.
- I will work safely by minimizing risks of injury or illness.
- I will prevent at-risk behavior whenever I encounter it.
- I will promote safety to others whenever possible.
- I will accept responsibility for safety as a free act of caring for others.

If the man pictured here lived by the ESA-AET team's five-step safety ethic, would he cross Diamond Drive and risk being hit by an automobile? Probably not. Would he cross against traffic if he did a risk/benefits analysis before crossing? Probably not. Is it worth saving the few minutes it takes to walk through the underpass if it meant a night in the hospital or even worse—perhaps months of rehabilitation for serious injury? Definitely not. Recently an employee was walking to her car after work; it was parked on the east side of Diamond Drive in TA-3. When she headed for the pedestrian underpass, she saw a man dodging traffic as he walked across Diamond. She chose to walk the longer route and use the underpass; they reached the parking lot at the same time. He risked injury and possibly death but didn't get to his car any faster than if he'd taken the safe route.

A culture of safety should be inherent in every individual here

Congratulations to the members of that ESA-AET team. What a great safety ethic! If everyone on that team accepts the five safety rules and attempts to work by them, they have changed the culture of their team. It's a great grassroots activity that we hope will spread. It looks like the ESA-AET team is "there"—in that culture of safety that so many of us find difficult to locate.

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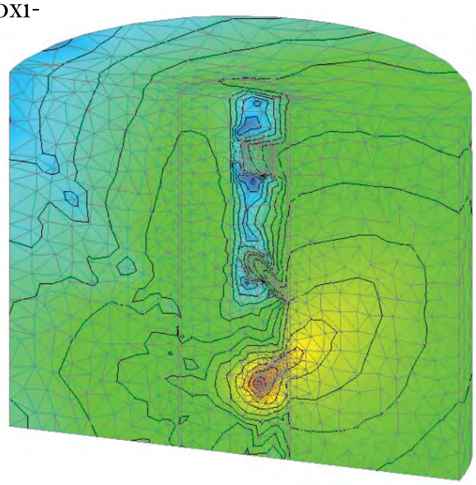
Point of View Continued from page 1

Intricate formulations are used to better approximate the "continuum" mathematics, but the point to be seen here is that these approximations require information that comes from a distance. Since this information is stored in discrete memory locations, it must be transported where it is needed. This foreshadows one of the thorniest issues of computer architecture—communication and the design of the interconnections amongst processors and memory.



A physics simulation actually proceeds in discrete time steps, much as spatial data are discretely represented. The values at the next discrete point in time are extrapolated from those at the current time. The time step, or the discrete change in time, is a critical parameter in the accuracy and stability of the numerical mathematics and another major driver in computer architecture. Large time steps allow us to finish the calculation earlier but can lead to unstable calculations.

In real calculations, however, accuracy and stability generally require time steps that are much smaller than we would like, leading to an immense number of algebraic operations. This is the origin of the "need for speed" that drives supercomputer architecture. The vast number of discrete points upon which the solution to the equations is approximated is the driver for the very large memories found in modern supercomputers.

These arguments, when carried through in a rigorous fashion, do nothing more than reduce some very complicated partial differential equations to a sequence of algebraic operations—no more and no less—and a code's job is to carry out this series of operations as fast as possible.

Currently our largest calculations sprinkle more than one billion discrete points over the area of interest and run for many days or months on our fastest machines. The large numbers of mesh points that are necessary for an accurate simulation require very large computer memories. The nature of the numerical methods used to approximate the original differential equations require gathering these data so the sequence of algebraic operations can be carried out. The sheer volume of data to be processed drives the need for speed. These fundamental demands on computer architecture have driven many of the innovative developments in computer architectures and are reflected in the vast array of machinery used at Los Alamos over the last 60 years.

Some Thoughts on Hardware

Computer hardware developed along many paths with unique and interesting ideas leading sometimes to Darwinian success and sometimes to extinction. Historically we can divide developments into several eras that reflected the state of the art of their time. The earliest architectures were "serial," with a single processor and a single memory device. The term arises from the serial nature of the algebraic operations. With a simple single processor, these operations were carried out one after the other, and the results were stored back into memory.

Efforts to speed up the processors took many forms. One of the most successful for large numerical simulations was the development of vector processors, pioneered by Cray. These processors set up a "pipeline" modeled on a factory assembly line and break the algebraic operations into a series of actions. A long "vector" of data moves along this assembly line; a finished product pops out at each tick of the computer clock. This worked quite well for the vast amounts of similar data in numerical simulations. So long as the pipeline was full, the processors were quite efficient.

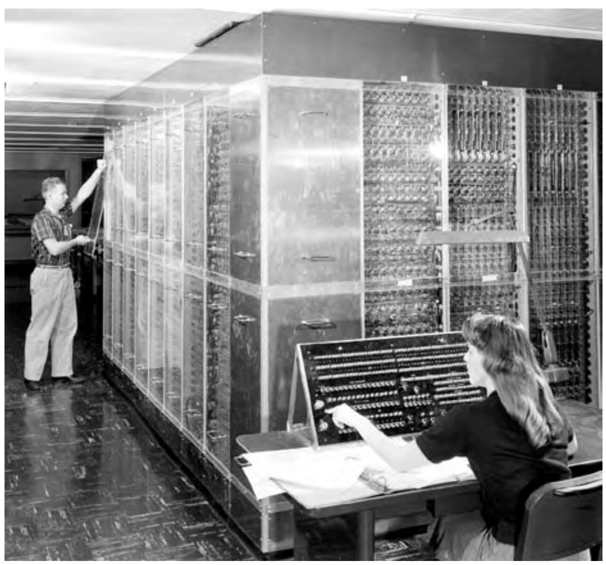
Multiple assembly lines can produce a product in parallel. Ganging together multiple processors to collaborate on a single problem is the basis of parallel computers. This idea is not mutually exclusive to serial processors or vector processors. In reality, most modern computers incorporate many of these ideas, and any individual machine is likely a hybrid with many of these architectural features.

It is instructive, however, to think of a historical timeline and eras in which each of these architectural features was transcendent.

Hardware's History at Los Alamos

A history of Los Alamos' involvement in high performance computing ranges from the earliest calculations on the ENIAC in 1945 to our latest developments in modern parallel supercomputers such as the "Q." Note that many of these developments are not the actual computers themselves but complementary technologies such as storage devices and networks that are indispensable to high performance computing.

Until the early seventies, supercomputers were primarily serial machines. With the founding of Cray Research, Inc., in 1972, the ideas of vector processors were implemented and the first vector machine, the Cray 1, was installed in 1976. Thus began a long and illustrious collaboration on the successive generations of Cray vector supercomputers that echoes to this day.



Cray vector supercomputers became the mainstay of Los Alamos production supercomputing with successive generations introduced until the mid- nineties. However, events conspired against Cray and the other custom-built low-production-volume companies that were Cray's competitors. Large federal spending on supercomputing declined in the mid-nineties after the end of the Cold War, and a possible inexpensive replacement loomed on the horizon—the commodity microprocessor-based parallel supercomputer. As buyers moved to less expensive computers based on commodity workstations and personal computer parts, Cray and its competitors struggled. Many did not survive, and vector supercomputers seemed to fade into the background, only to reappear recently.

Parallel supercomputing was in its infancy in the seventies with the development of machines like the ILLIAC at the University of Illinois. Los Alamos entered the world of parallel computing in the early eighties with a research project to build a custom computer called PuPS, but soon began to follow a collaborative approach with computer vendors with the installation of a commercially available parallel machine from Denlecor in 1983. The collaborative approach has been quite successful to the present day, with vendors supplying the machinery and integrating it while Los Alamos developed much of the software and wrung it out on users. Since the mid-eighties, the suitability of numerous parallel computers was investigated, ranging from the early Denlecor machine through computers from floating point systems and Thinking Machines to the modern range of machines from Hewlett Packard's Q and SGI's Blue Mountain, but a qualitative increase in activity began in 1995 with the Accelerated Strategic Computing Initiative (ASCI) program.

In 1995 ASCI became one of the most important drivers in the development of high performance computers at Los Alamos. With the end of nuclear testing, the DOE turned to numerical simulation as its main tool to maintain the nation's weapons stockpile. The ASC program, as it has become known, has supported codes, software, and hardware developments in the entire technology stack that we discussed earlier. The most promising architectures have been based upon parallel collections of the commodity processors mentioned earlier and have formed the basis of the ASC program.

> **The most promising architectures have been based upon parallel collections of the commodity processors and formed the basis of the ASC program at Los Alamos.**

We are now in the program's third generation of large parallel supercomputers with the installation of the 20-TeraOps Q machine from Hewlett Packard, an 8,192-processor computer. This machine is actually built in two parts. By one standard ranking of speed, these two machines are ranked second and third in the world. The first is currently the Japanese Earth Simulator, a modern reincarnation of the vector supercomputer pioneered by Cray! Thus begins one of the current controversies of computer architecture. Were we correct in riding the price versus performance curve derived from commodity microprocessor-based computers or should we have continued to invest our money in custom technologies like the Japanese? The answer is not entirely clear and probably never will be, but in general, we understand more about the characteristics of codes now and can say that the answer depends on the kind of code. By much more complex arguments than the simple discussion of code characteristics discussed above, we know that nuclear weapons codes make different demands on the hardware than climate modeling codes. Each favors a different architecture.

In the midst of the very visible developments of commercial parallel supercomputers came a quiet revolution of another kind involving commodity-based processors. Computing groups in government research laboratories and universities began to push the idea of commodity-based machines a level further and started to build computing clusters entirely out of commodity parts, both hardware and software. This revolution began at NASA's Goddard Space Flight Center in 1994. Thomas Sterling and Donald Becker built a cluster of processors interconnected with a standard commodity network, Ethernet. They layered a new publicly available operating system, Linux, with an emerging communications package, PVM, on top and created Beowulf.

For some years, Beowulf clusters and their derivatives have been a mainstay of institutions with smaller budgets and a propensity to tinker, but their performance has now developed into the "big leagues." Many major computer vendors are readying products based upon common microprocessors and standard interconnect networks that run Linux and other commonly available open source software. This is a revolution that we see soon for the next generation of supercomputers at Los Alamos and a qualitative change in the collaborative relationship that we have with our vendor partners.

We expect to assume a larger portion of the job of "integrating" the hardware and software together and will reap the benefits in the portability and reuse of our public software developments as we progress to new architectures in the future. The collaboration will involve more vendors and partners than the traditional bilateral relation that we have had with vendors in the past, drawing in many participants from hardware and software vendors as well as the open source community.

Recently Los Alamos, in conjunction with Linux-NetWorX Inc., built one of the largest commodity clusters, a 2048-processor Pentium 4 that is interconnected with Myrinet and affectionately called "Pink." This machine is a testbed for the open source software that will form the backbone of the next generation of high performance machines at Los Alamos. This software is a key element of our strategy and deserves discussion.

This machine will form the backbone of the next generation of high performance machines

Don't Forget the Software!

We return to our premise that hardware is not enough. The suite of available software forms the connection between the codes and the hardware. Of course, the codes themselves are software, but we mean the suite of programs that support the codes. This software suite includes the operating system that increasingly will be the commonly available Linux. Linux is now available on most microprocessors, but its most attractive feature is the open availability of its "source code" so that we can easily understand its inner workings and modify it to our purposes. Since it is not associated with a particular processor, it is expected to be the common operating system available for future architectures.

The interface to the storage devices is known as the file system. Storage of the vast amount of numerical data produced by these machines has become a bottleneck. It is not enough to produce the simulation and store it in memory; the data must be written to disk for safekeeping and future analysis. On many current machines, writing data to disk is many times slower than the actual processing of the data and stops the processor while it waits for the file system to catch up, although many file systems attempt to address this need. Currently we use production file systems provided by the major vendors for the Q machine and Blue Mountain, but we are collaborating on the development of two files systems that we intend to be portable to new machines, Lustre and Pannassas. These are developed on our Linux testbed.

Resource management systems (RMSs) are software that watch, allocate, and manage access to the processors, memory, and storage devices on a system. RMSs are interfaces through which a user interacts with the system by submitting, controlling, and retrieving jobs. They are key to managing the crowd of users that simultaneously need access, and they act as the system's traffic cop. There are several RMSs in common use for high performance computers. Currently, we use a very successful commercial product from Platform Technologies called LSF.

As the size of these computers grows and the large number of processes running simultaneously becomes unmanageable, the failure rate of hardware components rises to unacceptable levels, bringing down the fraction of time that the entire machine is available. We have sought ways to reduce the effects of these failures and increase the ability of a system administrator to cope with such large systems through a suite of open source software called Science Appliance. Elements of Science Appliance allow for fast booting of the entire machine, facilities for monitoring hardware for incipient failures, process management to simplify the life of a system administrator, and enhancements to file systems and resource management.

Codes require several types of software, including

- scientific libraries of code components that perform regularly used mathematical tasks and compilers that translate a code from the programming language in which it is written into machine instructions understood by the processor and
- modern communications libraries such as LA-MPI, the Los Alamos implementation of the Message Passing Interface that facilitate the data interchange amongst the processors efficiently.

Many additional aspects of the software environment are necessary to efficiently utilize these computers, and at least as much effort has been devoted to the software portion of the technology stack as to the hardware. We expect exciting future developments in hardware, but we must also keep in mind equivalent exciting developments in software. It is at least half of the story.

Where Do We Go from Here?

The future is unclear, but we must plan for it. Think of the journey to a distant mountain. Perhaps we can see to the edge of the woods and guess how the land looks beyond that, but we do not know how many cliffs and valleys lie afar. Our future might contain quantum or perhaps biological computers, topics presently spoken of with great excitement. Los Alamos supports research in these areas, and the prospects of increased speed and cost are so great with these revolutionary technologies that it is exciting and worthwhile to map out what that distant landscape might look like. Quantum and biological computing are so foreign to our current ways of thinking about programming that they may engender completely new approaches to software up and down the technology stack.

Closer to home, we see the path more clearly as an extrapolation of our current work. In the immediate future, we see Linux-based clusters as the stepping-stone to our next generation of very large parallel supercomputers. Our colleagues in other laboratories and research centers will continue to pursue the alternate direction of custom-built vector computers, but everyone will be watching innovative architecture developments represented by projects such as IBM's Blue Gene, the projects of DARPA's High Productivity Computing Systems program, and lesser-known efforts that combine radical processor design with technologies such as optical interconnects.

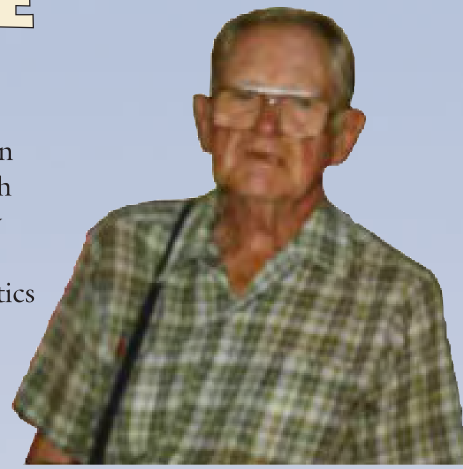
Los Alamos has been at the forefront of these developments for 60 years, and we plan to stay there. For those involved in the architectures of high performance computing, the past developments at Los Alamos have made us proud, and the future excites us even more.

Organizational Acronyms and Abbreviations

CCN	Computing, Communications and Networking Division
DARPA	Defense Advanced Research Projects Agency
DOE	US Department of Energy
DX	Dynamic Experimentation Division
ESA	Engineering Sciences and Applications Division
ESA-AET	Applied Engineering Technologies Group
ESA-WMM	Weapons Materials and Manufacturing Group
ESA-WR	Weapon Response Group
FWO	Facility and Waste Operations
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
LLNL	Lawrence Livermore National Laboratory
NMT	Nuclear Materials Technology Division
NNSA	National Nuclear Security Administration
RRES	Risk Reduction and Environmental Stewardship Division
UC	University of California

BACKWARD GLANCE

A-Bomb Trigger Man



Testing nuclear weapons is not without risk, as Los Alamos staff member John C. "Jack" Clark found out—not once, but three times in the early 1950s.

Jack Clark joined the Laboratory in May 1946, after being discharged from the US Army. He initially worked on ultrahigh-speed radiographic studies of detonation phenomena and strong shocks of metals. Within a year, he became Assistant J-Division Leader and subsequently Associate Division Leader. In these capacities, Clark also assumed the mantle of Test Director, a role that ultimately earned him the title of "A-Bomb Trigger Man."

On October 20, 1951, shot Able in the Buster-Jangle series failed to detonate. As Test Director, it fell to Clark to climb the tower and disarm the device. The shot was successfully fired three days later.

However, Clark faced a similar situation within a year when, on May 20, 1952, shot Fox in the Tumbler-Snapper series failed to detonate. Clark had ordered that the elevator in the tower be removed prior to the test. So after waiting an hour to see what might happen, he began the long rung-by-rung climb up the 300-foot-high Fox tower, carrying a hacksaw and accompanied by John Wieneke and Barney O'Keefe. Upon nearing the top, Clark used the hacksaw to open the door to the shot cab, which had been wired shut as a safety precaution. The bomb was quickly disarmed, and diagnostics showed that a malfunctioning measuring device had automatically blocked the firing circuit.

Clark's experience with nuclear weapons problems did not end with disarming the Fox device. During Operation Castle in 1954, Clark was among those forced to take refuge in a control bunker when the Bravo detonation doubled yield expectations and the blast wave and fallout covered the entirety of Bikini Atoll. Clark and company were eventually rescued by helicopter after radiation levels dropped sufficiently.

Clark left Los Alamos in March 1957 to work on the Atlas Intercontinental Ballistic Missile program at General Dynamics. When NASA modified the Atlas missile, he contributed to John Glenn's orbital mission. In 1963, Clark became a Foreign Service Officer serving as the scientific attaché in the United States Embassy in Cairo. He retired from the State Department in 1966, just prior to the cessation of diplomatic relations with Egypt. Jack Clark died in July 1993 at age 98.