LAWRENCE LIVERMORE NATIONAL LABORATORY

THE GIANTS OF THE NUCLEAR TESTING ERA

A Series of Notebooks from the Pioneers

The Works of Robert Clough

Lawrence Livermore National Laboratory

This work is part of a series sponsored by the Archiving Data and Management (ADAM) program within the National Nuclear Security Administration's Office of Engineering Stockpile Assessments and Responsiveness (NA-115). The ADAM program is responsible for preserving the data and irreplaceable knowledge from the nuclear weapons testing era. This information continues to be used to support the current and future stockpile and also train the next generation of weapons scientists with no nuclear testing experience.

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The Works of Robert Clough

> *Engineering makes concepts a reality. Robert Clough drove the engineering side of the Weapons Program, so he was pivotal in putting these weapons in the stockpile and maintaining them."*
>
> — Derek Wapman, Associate Deputy Director for Stockpile Modernization
> Lawrence Livermore National Laboratory

> *Our job was to think the unthinkable, say the unsayable, do the undoable."*
>
> — Robert Clough, Retired Weapons Engineer
> Lawrence Livermore National Laboratory

FOREWORD

I am pleased to introduce this third volume of Lawrence Livermore's Giants Notebooks knowing that Robert (Bob) Clough is the focus. I started work as an engineer for Lawrence Livermore straight out of school. Bob ran the Weapons Engineering Division then, and by the late 1980s I reported directly to him. Bob mentored me, giving me assignments to observe my capabilities and opportunities that advanced my career.

At that time, the United States and the Soviet Union were at the tail end of the Cold War. The country poured money into the Weapons Program to ensure the United States remained on top. Lawrence Livermore's Weapons Program had to deliver.

Our mission was clear, and the workload was high. Bob's standards were high as well. When working with Bob, the recipe for success was to be on your game, have your story straight, and state a good reason for what you wanted to do.

I found what he asked of us to be reasonable—perhaps, in part, because I could relate to Bob. My parents and Bob's parents lived through the Depression. People were shaped by that experience. Also, Bob and I were both comfortable working with tools. I had worked on my own cars through college, and Bob handled all his own home repairs. Engineers with that kind of hands-on experience approach projects with a unique mindset.

Without Bob's leadership, I don't think we could have achieved what we did—certainly not in the timeframe we did and at such high quality. In fact, I don't believe we would have the quality of the stockpile that we have today without Robert Clough and the management team he developed.

Derek Wapman, Associate Deputy Director for Stockpile Modernization[1]
Lawrence Livermore National Laboratory

ROBERT CLOUGH: A NUCLEAR WEAPONEER

Robert (Bob) Clough may well have been born to be an engineer. His father owned his own mechanical engineering firm and machine shop. From an early age, Clough was surrounded by engineers and builders, learning to work well with tools himself[2].

Going to college was a given. Clough's parents had met at the University of California at Berkeley, and they stressed the importance of an education because earlier generations had not been offered the same opportunities to advance. He attended his parent's alma mater, as did his younger sisters, and met his future wife at the university as well[2].

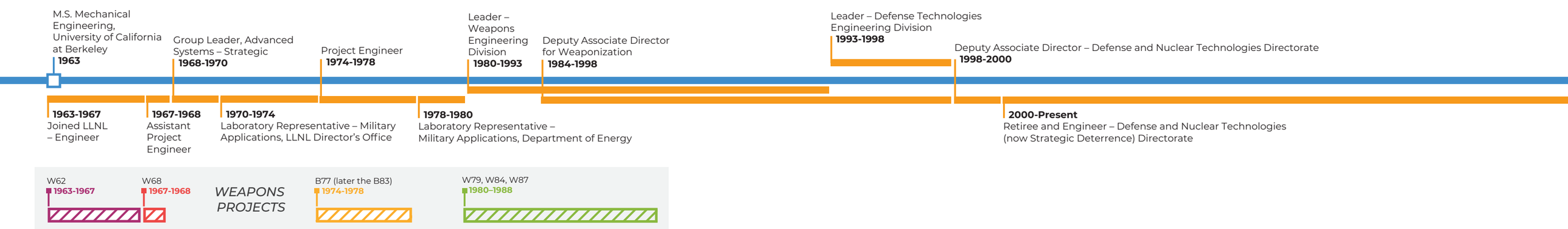
Clough took a summer job at Lawrence Livermore National Laboratory during his undergraduate years on the recommendation of professors who worked at the Laboratory. He went on to earn a master's degree, presenting a thesis on plasma jet facilities. Of course, Clough designed, built, and tested the plasma jet facility himself[2].

Living during the peak of the Cold War between the United States and the Soviet Union and working at the Laboratory through college, Clough was drawn to a career in the Weapons Program. As an engineer, Clough stood apart from the staff of mostly scientists. "The physicists were in charge," said Clough. "The engineers had to show they could contribute. I had experience working with nuclear materials and understood their engineering qualities—skills that worked out well for me. I called myself a nuclear weaponeer."

Over his 37-year career at Livermore, Clough's engineering work supported development of the W62, W68, and B77 (later the B83). He represented the Laboratory on the Department of Energy's (DOE's) Office of Military Applications—both in the Director's Office and in Washington D.C. Clough rose from engineer to become the Division Leader of the Weapons Engineering Division (later Defense Technologies Engineering Division (DTED)) in the Mechanical Engineering Department and Deputy Associate Director for the Weaponization (W) Program with responsibility for the W79, W84, and W87 programs[2]. He said, "From the first set of assignments, I knew how the Lab operated. When I got to the end, it was someone else's turn to be the leader."

As a retiree, Clough supported the Laboratory's Red Team—a group of retired weapon designers and engineers selected to evaluate the stockpile assessment process. He maintains his license as a Registered Professional Nuclear Engineer, and he passed on the value of education to his three daughters, one of whom is a computer engineer. And Bob has never stopped building, continuing to handle repairs on his rental properties[2].

ROBERT CLOUGH[2]



EARLY CAREER: W62 AND W68

Clough started his Lawrence Livermore career in 1963 just as the United States, the United Kingdom, and the Soviet Union had agreed to the Limited Test Ban Treaty prohibiting nuclear weapons testing in the atmosphere, underwater, or outer space. At the same time, the U.S. had focused on developing weapons capable of withstanding anti-ballistic missile (ABM) attacks by both hardening the individual warheads and providing multiple warheads for each missile[3].

For his first weapons engineering assignment—Phase 3 of the W62 warhead—Clough and fellow engineers detailed parts fabrication and testing based on the conceptual design provided by physicists in the Weapons Program. "The laboratories had learned a lot from nuclear testing. In the absence of high-yield testing, weapons engineers became more capable in calculating stress, strain, deformation, and thermodynamics," said Clough. The W62 would be noted for material hardening that offered protection against ABM attacks in addition to its suitability as a warhead in a multiple independently targetable reentry vehicles (MIRVs) system for the Minuteman III missile[3].

The W62's parts were made in different plants—Kansas City, Rocky Flats, Y-12— as well as plants since closed—Pinellas in Florida and Mound in Ohio—that were, at the time, focused primarily on nuclear weapon products. All parts were produced and then shipped to be assembled at the Pantex Plant in Texas for delivery to the military as a warhead. All sites required coordination with the Laboratory, not to mention the Livermore-to-Sandia military interface requirement to ensure military logistics-training preparations and certification with the Defense Nuclear Agency. Every site came to know and respect Clough's communication, cooperation, and competency, and his name remains recognizable among senior levels of the complex for his drive to get the job done right the first time.

The Laboratory's engineers and design physicists tested components and subcomponents for resilience to antimissile weapons and to the vibrational, thermal, and shock environments associated with stockpile maintenance and possible delivery to target[2]. "We worked in small groups—maybe eight engineers—and needed to understand every part of the process," said Clough.

Retired weapons engineer Lee MacLean worked on the W62 project as a summer student. Clough was his first boss at the Laboratory. "I continued on to graduate school working part-time at Lawrence Livermore and remaining in Clough's group. I wanted to do what I saw Bob doing," said MacLean.

As Clough's weapon design knowledge expanded, he moved on to the W68 project, ultimately becoming a group leader with opportunities to consider even greater weapon capabilities for countering ABM attacks[2]. The W68—a small, yet high-yield warhead—enabled MIRVs by conforming to the small C-3 missile platform selected for deployment[3].

For both the W62 and W68 projects, Clough worked with Livermore weapon designer Seymour Sack, featured in the Laboratory's first Giants Notebook publication[4]. "Seymour was the acknowledged weapons expert," said Clough. "I was the design engineer for two of Seymour's experiments, and he gave me a view of design that had not been seen in the W (Weapons) Division before. He didn't mince words, but that was what we needed to hear as we sought to do new things."

The 1970 deployment of the W62 warhead for Minuteman III and the W68 warhead for C-3 marked the success of a coordination effort that included designers, contractors, and military representatives. Clough's next role would place him at the intersection of all three interests for future weapon projects.

PHASES OF WEAPON DEVELOPMENT

Phase 1: Concept Study

Phase 2: Program Feasibility Study

Phase 2A: Design Definition and Cost Study

Phase 3: Full-scale Engineering Development

Phase 4: Production Engineering

Phase 5: First Production

Phase 6: Quantity Production and Stockpile Maintenance and Evaluation

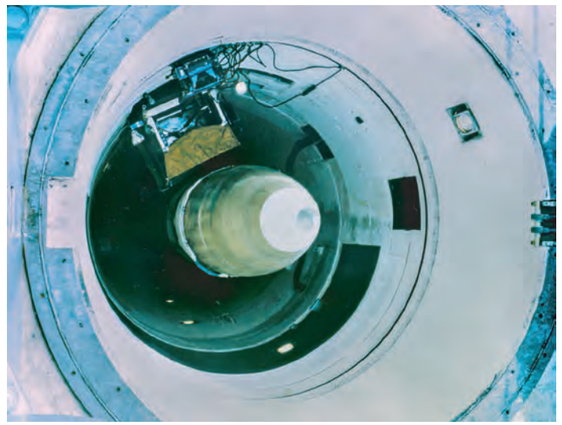
THE ROLE OF ENGINEERING IN WEAPON DESIGN

Physicists and engineers combine their very different but complementary skills and experiences to design weapons for the stockpile. Physicists start the process by devising concepts for a proposed weapon and then supporting their ideas with calculations and initial tests. Chemists and material scientists evaluate the design for material compatibility and aging over time in storage and to better understand new materials developed for weapon use[5].

Engineers transform designs, calculations, and test results into a tangible weapon that survives exposure to intense environments and still works as designed when deployed. "Engineers think in three dimensions and sketch realistic designs," said retired weapons engineer Lee MacLean. "Sometimes we have to say, 'That just won't work.'"

"Engineers create a bridge between the concept and the user," said weapons engineer Derek Wapman. "We work with the scientists to weaponize the design. We interface with Sandia National Laboratories to develop the weapons, the production plants to build the weapons at the intended yield, and with the Department of Defense to arrange for tests and other logistics. At Lawrence Livermore, these partnerships are tight. That's why our designs are so successful."

The Poseidon C-3 missile launched from a submerged submarine.



In the 1970s, Minuteman III missiles with Livermore-designed W62 warheads were deployed in silos at U.S. Air Force bases in three states.

LABORATORY–MILITARY COORDINATION AND THE B77

Starting in 1970, Clough served as the Laboratory's representative on aircraft-carried weapons under Director of Military Applications, Charles "Chuck" McDonald. Working out of the Laboratory Director's Office, Clough coordinated efforts among A Division (responsible for "secondary" or thermonuclear design), B Division (responsible for "primary" or fission design), and W Division (responsible for engineering design) to unite all elements of weapon design[2].

In this role, Clough led Phase 2 for the B77, creating illustrative drawings of designs from A and B divisions to facilitate discussions with military representatives. Clough recalled that most Phase 2 work was marked with compromise as physicists, engineers, and the military guided the design toward a solution to meet all goals as closely as possible. "The question was, 'How do we design a device that stands up to the vibration and delivery modes from aircraft?' (Seymour) Sack and I provided direction to the engineers in the group on the B77 project," he said. "We made a detailed design and drawings, worked with the plants to get the parts, and designed the nuclear and engineering tests."

"Clough put together the Laboratory's proposal," said George Miller, former Laboratory Director. "The B77 was a complicated system. All the military's requirements had to be met in one package rather than multiple versions." Added Clough, "We were dealing with people who had been weapon officers in the armed forces and could offer experience from those assignments." The range of experiences on the B77 team led to a variety of design ideas that were evaluated and accepted. "We made the military happy, and that made me happy," said Clough.

Clough then offered to complete the B77 design and buildout—Phase 3—with his engineering team. He returned to project engineering and applied what he had learned about each element of the design from his earlier collaborations with Seymour Sack. A and B Division staff joined the team as well[2].

"Working with Bob and his team as a designer, I quickly came to appreciate that he would both challenge my assertions, offer positive suggestions, and work very hard to implement the decisions that were made – the marks of an incredible teammate," said Miller. "I had done some physics shots, but the thought process in W (Weapons Division) was very different. W yields a product that lasts 25 or more years." Miller added that the project manager for a weapon project had typically been a physicist. "I could see right away that Clough was organized, disciplined, and creative. The interaction between physics and engineering was intense, and Clough was at the center. He thought like a physicist. He understood what was at our disposal and what physicists worried about. He also solved the engineering problems to maintain the integrity of the physics we wanted to maintain."

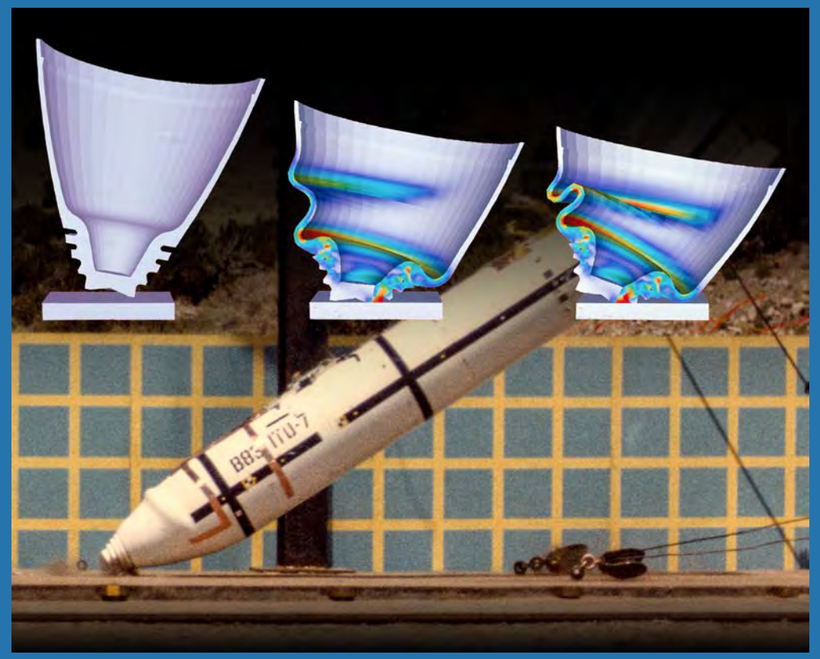
Miller noted that the already complex project was made more difficult when a testing ban loomed. "B77 yields were above the test limit," said Miller. "We felt pressure to finalize the design and do a full test. By my reckoning, this was one of the most intense periods of Laboratory activity associated with the Nuclear Weapons Program."

The effort would end, however, when the Carter administration stopped the B77 project citing its size and expense. By this time, Clough had become accustomed to the effects of involvement by different government bodies on the Weapons Program and the balancing act required to satisfy all stakeholders[2]. "Congress wanted more and newer features. The Department of Energy wanted a less expensive approach to yield different capabilities. We understood that weapons need to be maintained and sometimes replaced," he said.

Ultimately, the B77 design and engineering efforts were not in vain. Under the Reagan administration, some B77 design features found their way into a modified design, the B83.

THE B83 AND DYNA3D

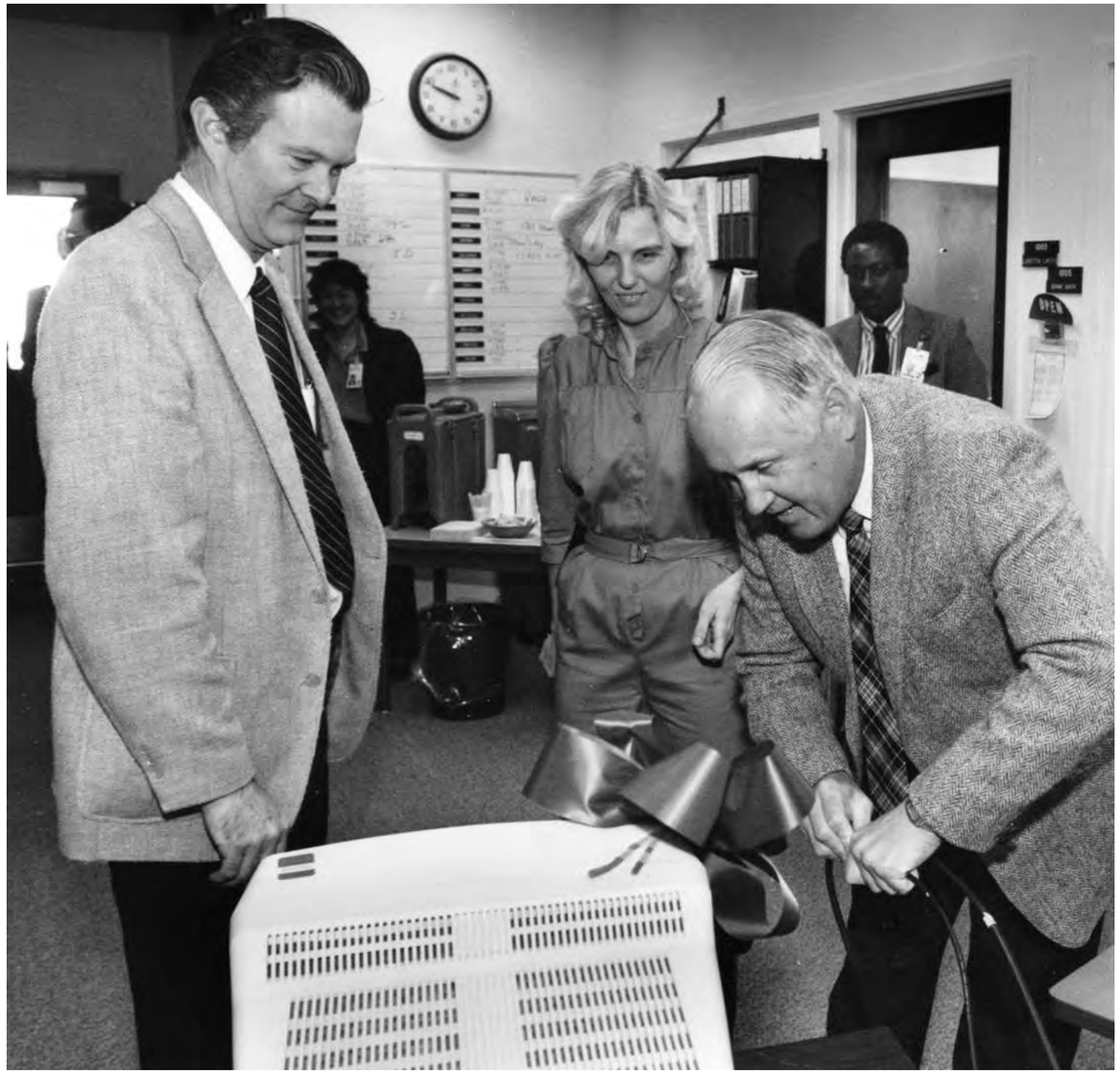
Aircraft-carried like the B77, the B83 offered the capability to fly over a target. "Given the world climate, I felt America needed that kind of weapon at the time," said Clough.



A DYNA3D calculation shows the crush-up of a B83 strategic bomb's nose cone upon impact.

Retired weapon designer Kent Johnson recalled, "As division leader during the B83 final development, Clough was responsible for implementing the engineering features that ensured the bomb would survive the drop." Johnson described the bomb's physics package as "complex," as expected to meet difficult engineering challenges. "To be successful, the strategic aircraft carrying the bomb would penetrate air defenses, fly at close to the speed of sound, drop at low altitude[6] to release the bomb, and then fly in a way that the air crew would escape before detonation[7]," he said. Engineers needed a way to reliably model the survivability of the bomb given the intensity of its impact with the ground.

In response, Clough and his team developed the DYNA code to model the B83's impact survival, saving the time and millions of dollars required for trial-and-error crash testing. "Clough was a major supporter of computer engineering at a time when the integration of physics and computational engineering was not as prevalent," said George Miller. "There is a fine line to walk in weapons engineering. You can't take too much risk, but you don't want to do the same thing over and over again. You want new ideas and tools." Later, the unclassified DYNA3D code was transferred to private industry, particularly to automotive and aircraft companies that applied the code in crash simulations for improved safety designs[8].



Clough (left) with Sharon Schumacher and Bob Godwin in 1988 as they welcome the Controlled Material Tracking System for tracking parts and materials.

ENGINEERING LEADERSHIP

In the 1980s, Clough moved into leadership roles for engineering and, later, weaponization at Lawrence Livermore. "I was in a unique position at that time. I managed both the people in engineering and the money in the Weapons Program," he said.

The Laboratory supported two physics divisions—A & B—and two engineering divisions—device and weapons engineering. Device engineering supported Phase 1 and Phase 2 feasibility studies, preparing devices for testing at the Nevada Test Site (now the Nevada National Security Site). Next, projects moved to Phase 3 for engineering development, the charge of the Weapons Engineering Division[9].

From 1980 to 1993, Clough led the Weapons Engineering Division and made a point of knowing every person on staff—225 people at that time. Lee MacLean, who returned from other Laboratory assignments to work with Clough in the early 1980s, recalled Clough's managerial skills. "He was strong technically, and he protected the division. A number of project engineers requested assignments with Clough. I look back fondly on that era. Our work was satisfying, and we engineers enjoyed a lot of opportunities."

During this period in Clough's career, weapon systems turned over every seven years. A number of weapon design Phase 3s were in development: B83, W82, W84, and W87[1]. Engineers had to consider conditions of weapons launched from artillery, cruise missiles, and intercontinental ballistic missiles at the same time[9].

Each Phase 3 came with its own strict timeline, and the engineers knew to expect surprises that could delay progress[9]. "The idea was to work yourself out of a job in Phase 3," said MacLean, who became the W87 project engineer. "There was no slowing down. We were in a very busy and very productive era with three or four Phase 3s going simultaneously. The world was changing. We had a strong sense of what needed to be done at that time."

For the W87, MacLean, Clough, and their colleagues addressed the potential vibration and temperature extremes anticipated for the system as well as the practicalities of transporting the weapon from Pantex[2]. MacLean spent time in Nevada with Clough testing devices with weaponization features. "Our designs had to survive long range missiles as well as time in the stockpile," he said. "Bob had that burden on his shoulders."

Clough was division leader when the W87 was selected for continuing deployment in the stockpile, leading to the W87 Life Extension Program (LEP). In 2001, Clough was among Livermore staff recognized for leadership in the W87 LEP at a ceremony marking the project's success in refurbishing the first warhead without nuclear testing[11].

ENGINEERING LEGACY

Peter Raboin, W80-4 LEP Program Manager, joined the Laboratory in 1989. He recalls a design that yielded a concern, identified by nuclear testing, about marginal behavior at aged condition. “Clough swung into action, standing up multiple teams, collecting all ideas,” he said. “The revised design was completed in a few months.”

Raboin reflects that Clough and his contemporaries trained the engineers who are nearing retirement age in the 2020s[10]. “I was surrounded by people with decades of experience, solid role models. I understood what it took to succeed in the W Program,” he said.

"Working with Bob from the time he was a program leader through his role as Deputy Associate Director, I valued his straightforward approach, his willingness to challenge my ideas, and his dedication to getting the job done." said Miller. "Bob always had my unwavering trust in even the most trying circumstances. His loyalty to the Laboratory was unsurpassed, even when he disagreed with a decision, such as the Laser Directorate's effort into Demo '85 (for the Atomic Vapor Laser Isotope Separation Production Plant). Despite his views, he actively encouraged the best people in W Division to join the effort and support that decision."

In the mid-1990s, Clough was asked to write the first set of operational capabilities for Lawrence Livermore in response to a Department of Energy call for more formalized Laboratory operations[6]. Clough was selected because of his extensive knowledge of how the Laboratory operated and his tried-and-true approach of operating streamlined, successful teams. “The Laboratory had always operated with discipline, but not always with formality,” said Miller. “It would have been easy to add bureaucracy in response to DOE’s request. We trusted Clough with the job because he understood that disciplined operations didn’t require unnecessary paperwork.”

CALTRAP

While in leadership roles, Clough represented the Laboratory in Washington D.C. and proposed innovative technologies such as one he named "CALTRAP." The name reflected both his background at the University of California at Berkeley (nicknamed “Cal”) and a term used in the Middle Ages for an arrangement of spikes that slowed the progress of mounted troops[2]. "Bob often said, he bled true, Cal Berkeley blue," said Miller. "His loyalty and support of the University of California and its values in the management of the Laboratory were unwavering." Despite moving through reviews at Lawrence Livermore and Sandia national laboratories, the project was not funded.

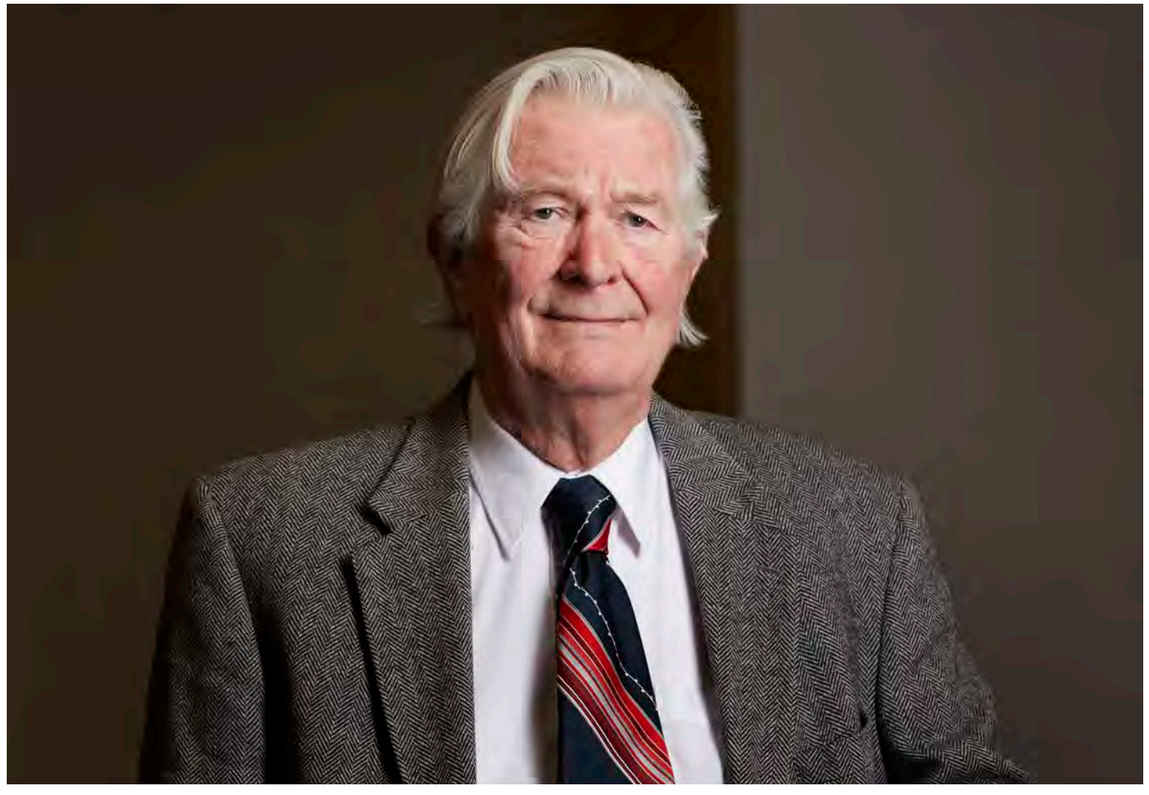
RETIREMENT: SAFE KEEPING

On retirement, Clough was assigned a unique project: managing safes filled with confidential documents when other staff retired. At one point, recalls Clough, so many safes had been transferred to the storage room that he expressed concern about the stress on the floor supports. When safes were determined to be too old for reliable use, Clough carefully shredded personal items, moved unclassified documents to older safes, and filled new safes with confidential materials[2].

In 2008, Clough and fellow retirees Dan Patterson and Leon Keller discussed their experiences as weapon designers during a meeting between Livermore's Strategic Deterrence organization and a delegation of UK scientists and government officials. The meeting recognized the close collaboration of the U.S. and UK in addressing their respective stockpile stewardship programs[12].

Clough has also joined retired weapon designers, such as fellow Giant Dan Patterson and other weapons engineers, to evaluate device tests yielding unexpected results. “I enjoyed learning more about the physics design elements of the components,” said Clough. “The work was satisfying. I felt we were making a major contribution.”

He added, “There’s a fine line between success and failure. Going back to the elemental and building up to something you can use makes the difference. That’s still true today. If you don’t pay attention to the details, they’re going to bite you.”



LEGACY & IMPACT

> "He is a very loyal individual both to the people he worked with and to the country. He had a calling. He understood the importance of the job and responded."
>
> — Lee MacLean, Retired Weapons Engineer

> "He had a method, a drive, and a willpower that could overcome setbacks and produce the right design."
>
> — Peter Raboin, W80-4 LEP Program Manager

> "Both personally and through his leadership, Bob was the epitome of the engineering excellence that turned the ideas of Johnny Foster and Harold Brown and the acumen of Seymour Sack and Dan Patterson into the high quality, long-lived, and exceptional warheads that characterize today's stockpile. They are engineering marvels and remain the standard by which the rest of the free world's endeavors are measured. He understood and respected the responsibility that engineering had as the fabric of the Laboratory."
>
> — George Miller, former Laboratory Director

> "Clough set the bar high and created the thumbprint of what is today's Weapons Engineering Program. The culture is built not only on high expectations but on a flat and lean organization—no fluff, no focus on titles. Clough's legacy lives on in the excellence of the program and the leaders who patterned themselves after him."
>
> — Sue Taylor, Retired Weapons Engineer

WORKING WITH ROBERT CLOUGH

Robert Clough: *"I had a reputation as being difficult. Yes, I pushed people hard. We had tough problems to solve."*

Sue Taylor: *"Clough had high expectations and drove his staff to deliver, but he cared deeply about his staff as well. I witnessed his concern and actions when colleagues fell ill and were away from home on Laboratory business. Clough was very attentive and provided resources for the employees and families."*

George Miller: *"Bob was undaunted by bureaucratic obstacles. When the DOE and DOD thought high-fidelity flight tests were unnecessary, expensive, and a diversion from more important activities, Bob pushed the need for them through the system, and he was right to do so. He was strong and yet humble and unassuming at the same time—a person of strong principles, values, and character—with a great sense of humor."*

Peter Raboin: *"Clough could talk about difficult topics in an objective, professional way with no hesitation. He would dive right into the abyss. He taught me valuable lessons about having difficult conversations."*

Kent Johnson: *"He took the weight of his responsibility on his shoulders. When others did not live up to that standard, he let them know it."*

Lee MacLean: *"He demanded excellence. Bob knew our strengths and weaknesses, and he demanded that we stay prepared and ready for a quiz. He challenged us, made sure we thought things through."*

Derek Wapman: *"Clough was not everybody's cup of tea. He was very demanding and didn't suffer fools gladly. But without his drive and determination, we wouldn't have been successful."*

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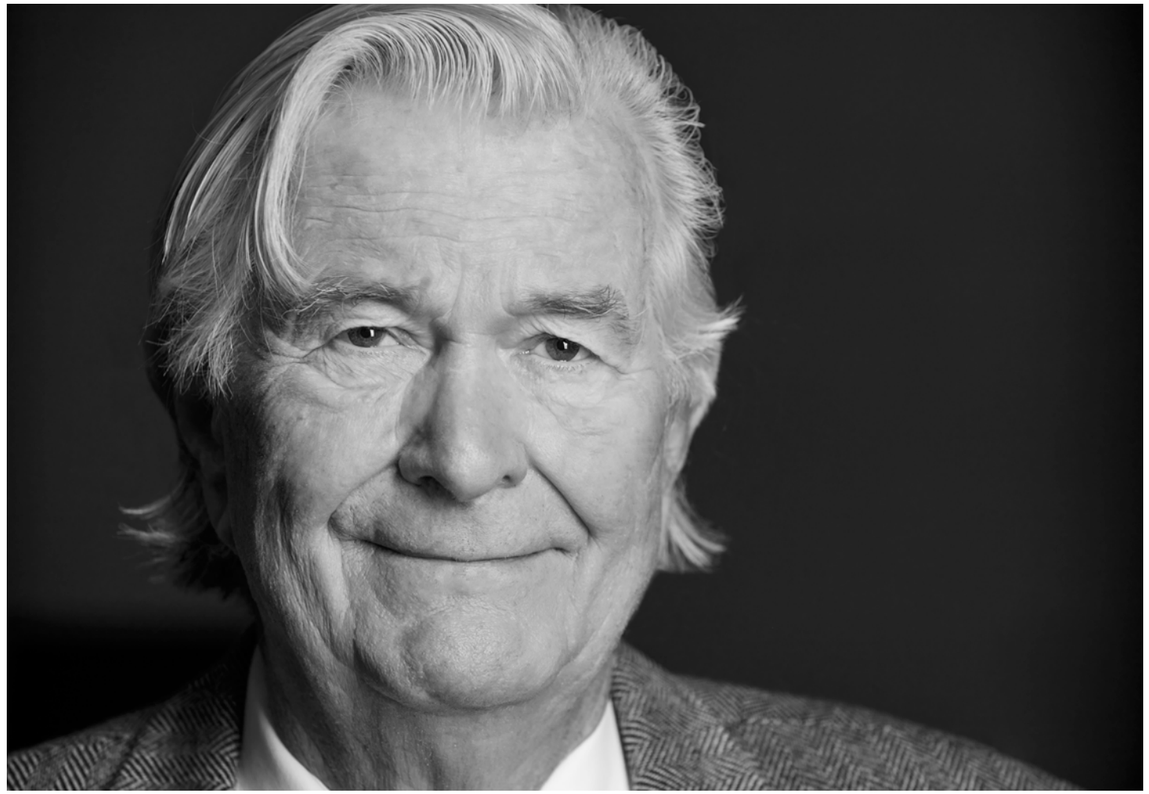

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