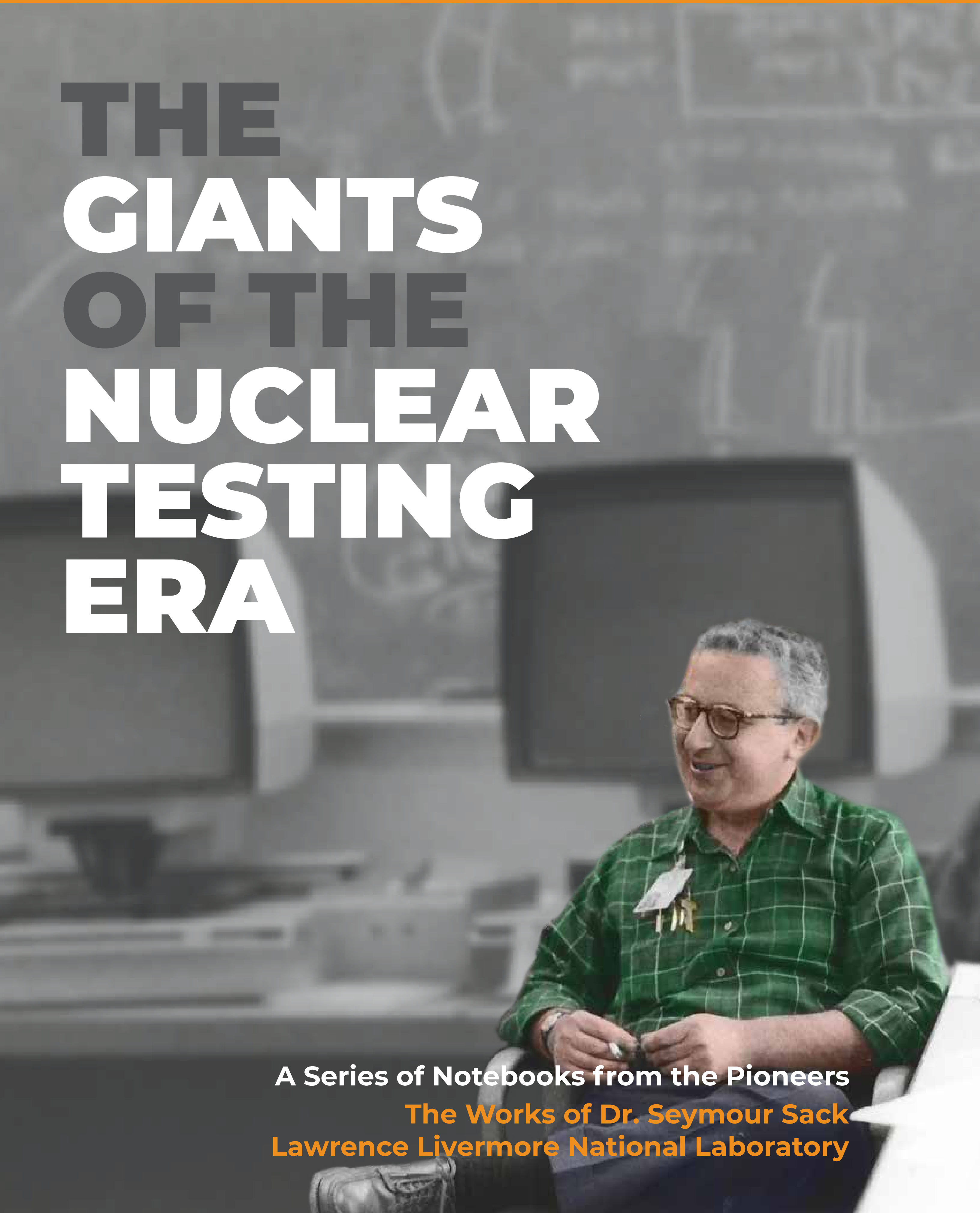
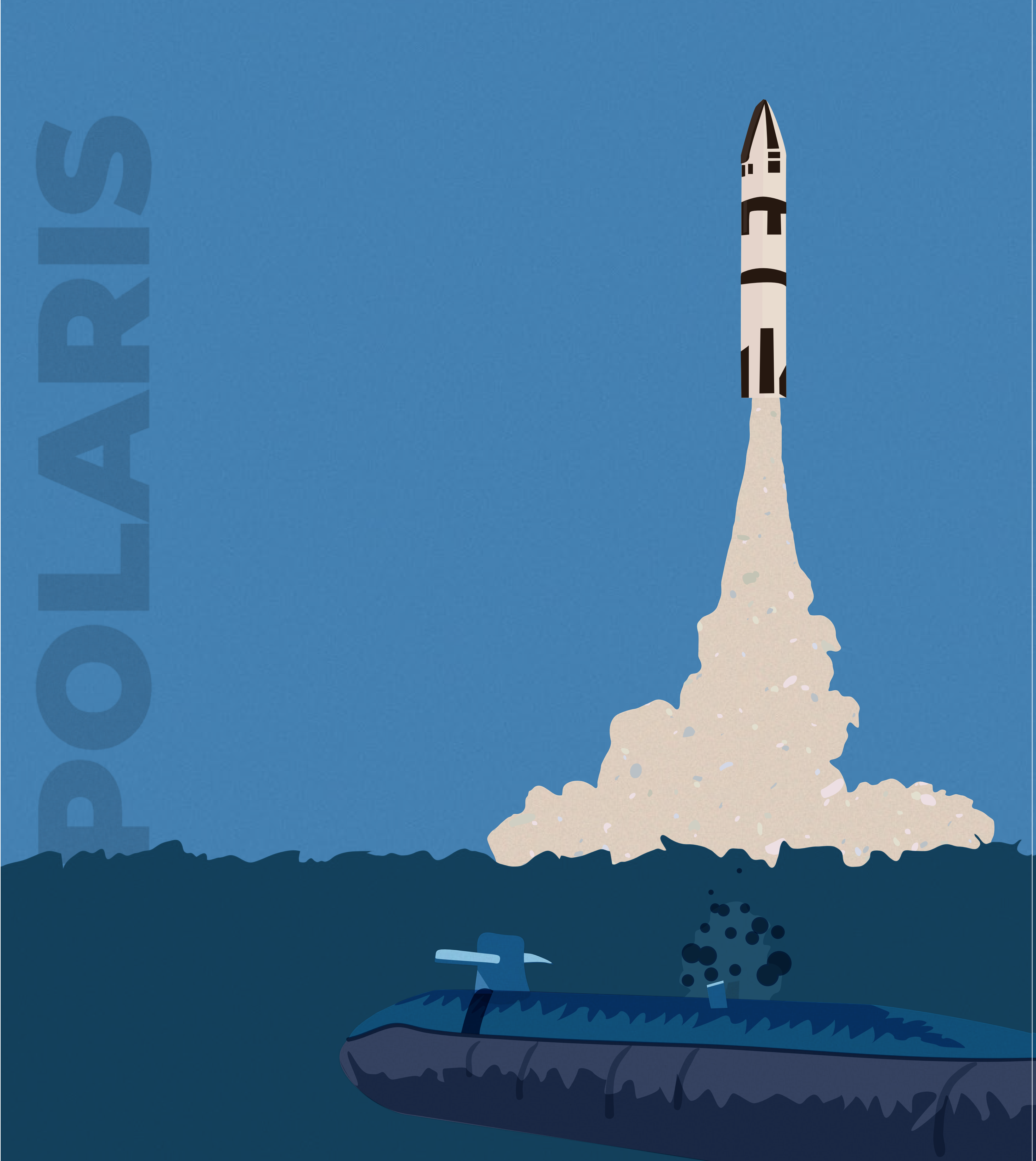
THE GIANTS OF THE NUCLEAR TESTING ERA



A Series of Notebooks from the Pioneers

The Works of Dr. Seymour Sack

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.

THE GIANTS OF THE NUCLEAR TESTING ERA

A Series of Notebooks from the Pioneers

The Works of Dr. Seymour Sack

“Seymour leaves behind a large family of scientists who owe to him the insistence on excellence he passed on to the design community. **We stand on the shoulders of this giant and we shall miss him.**”

—Mike Dunning, former acting principal associate director, Weapons and Complex Integration (WCI) Directorate[1]

PREFACE

Seymour Sack had a truly remarkable career and his influence is still manifest today. This document highlights some of the seminal contributions he made in support of national security; contributions that changed the very nature of nuclear weapons and enabled the modern U.S. stockpile.

It is also important to understand how Seymour was able to achieve so much success (lessons that helped me throughout my career). When I joined the Laboratory as the fifth member of his group, we were putting three different weapons into the stockpile simultaneously! His leadership was key to our success. He inspired our small team, giving each of us the freedom to carry out our role while developing new approaches to do it better. He also inspired the best from the full resources of the Laboratory. He understood that bringing a design concept to fruition required working closely with the experts in many areas: the simulation tools needed to develop and optimize the concept; the engineering, materials, and manufacturing to ensure that it can be built; and testing under stressful conditions with diagnostics that were sensitive to the key issues.

Seymour's technical expertise was both deep and broad. He held himself to a very high standard and expected that of others. He once told me that we each must be our own best critic—no one else will focus more on what each of us is doing. He was always ready to share his knowledge to guide others. While he could be a harsh critic of sloppy thinking (beware the "purple pen"), he was always patient with those who wanted to understand. He invariably would guide us to the issues behind our questions before letting us focus on an answer.

Seymour was open to new ideas when he could see how they could help accomplish the mission, not just because they were new or better. He also used his experiences to establish how much risk to take in a design intended for the stockpile, even when a competitor was bolder. As the nation moved into an era without nuclear testing, this led me to establish explicit technical metrics for the LLNL program around margins and uncertainties (referred to as QMU) that are still practiced nationally today.

Seymour had a unique blend of skills and many remarkable accomplishments that made him a Giant of the Nuclear Testing Era.

Michael R. Anastasio, director emeritus
Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL)

DR. SEYMOUR SACK | 1929–2011

Dr. Seymour Sack was one of the foremost designers of nuclear weapons. His imprint can be recognized in the first stages of the two-stage thermonuclear devices within our enduring stockpile. His design programs introduced insensitive high explosives, fire-resistant plutonium pits, and other state-of-the-art nuclear safety concepts.

In the late 1950s, he developed two-dimensional (2D) design codes and in the early 1960s applied them to the design of the safe, modern primary deployed in the Polaris warhead. During the 1960s, he designed primaries for the first "miniature" bombs deployed in the Poseidon submarine-launched ballistic missile and the Minuteman intercontinental ballistic missile. These designs were prototypes for the warheads developed by Los Alamos and Lawrence Livermore in the 1970s and 1980s.

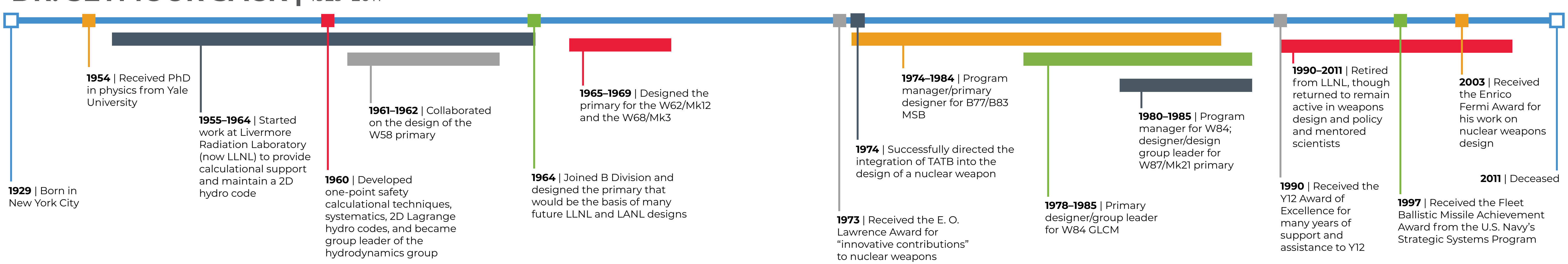
During the late 1970s and early 1980s, Sack turned his efforts to the conception and realization of the modern, extremely safe, air-carried nuclear weapon. The potential for aircraft accidents with catastrophic consequences made this a critical need, which Sack championed for the weapons stockpile. He designed the primaries for both the high-yield gravity bomb and the ground-launched cruise missile. Simultaneously, he directed both development projects. On these projects, Sack designed the device that first successfully demonstrated the use of insensitive high explosive, and developed the first fire-resistant pit, thereby greatly enhancing the safety of nuclear explosives in crash and fire accidents.

Finally, in the 1980s, all of these safety innovations were brought together for the first time in a strategic missile warhead known as the W87, to be deployed as a MIRV system on the MX missile known as the Peacekeeper. The Peacekeeper missile system was discontinued as a result of treaty negotiations, and removed from the nuclear inventory. However, the W87 was found to be compatible as a single warhead with the then deployed Minuteman missile system. The W87 continues today to be the safest, most advanced warhead in the active stockpile.

Over the course of his career, Sack maintained extremely high technical standards across a broad spectrum of fields. He had a wide reputation for clear thinking and an uncanny ability to distinguish the essential from the unessential when it came to matters relevant to nuclear weapons. When he retired in 1990, he remained extremely active in nuclear weapons design and policy issues.

Throughout his 35-year career and decade of semi-retirement, his hallmark was his technical expertise, combined with dispassionate, insightful, and honest reasoning. Sack remains an invaluable national resource.[2]

DR. SEYMOUR SACK | 1929–2011



SEYMOUR AS THE COMPLETE DESIGNER

While Sack was a theoretical physicist by trade, he emerged as one of the foremost designers with a comprehensive understanding of all nuclear weapons design aspects. From metallurgy, manufacturing, and materials to safety, use control, computer modeling, data collection and interpretation, and weapons design, Sack understood it all, and can aptly be thought of as a "complete designer." This knowledge is evidenced through his thorough handwritten notes, the impressive "Vault Tour for Dummies"[3] that he authored, and his expert mentorship that inspired many young scientists.

> "His high technical standards, innovative approaches, and continual mentoring of LLNL scientists over many generations will continue to influence national security well into the future."
>
> —Michael R. Anastasio, director emeritus, LLNL and LANL[4]

"He is an outstanding and unique applied scientist whose influence is imprinted on all aspects of the modern U.S. nuclear stockpile and on the overall weapons program," says former LLNL Director Michael R. Anastasio. "His high technical standards, innovative approaches, and continual mentoring of LLNL scientists over many generations will continue to influence national security well into the future."[4]

Sack was one of many individuals who supported the Laboratory's tradition of collaboration by building multidisciplinary teams, pulling in experts from within LLNL and from the Department of Energy, Department of Defense, and the plants. His comprehensive understanding of nuclear weapons design can be attributed in part to these diverse partnerships.

Seymour Sack (center) pictured with Roger Batzel (left) and Tom Wainwright (right).

In addition, Sack not only designed warhead components, but also designed complete, reliable, and manufacturable warheads for the stockpile. His weapon design programs introduced many innovations, including insensitive high explosives, fire-resistant plutonium pits, and other state-of-the-art nuclear safety elements. His design concepts are found in all U.S. stockpile weapons—not just those from Lawrence Livermore. Sack designed nuclear tests to examine most, if not all, of the basic problems of safety and stability in environments of varying difficulty, as well as the idea of margins and how to anticipate and prepare for the results of uncertainties under adverse conditions. His own designs showed this stability and long-term viability of the stockpile. "Seymour was the master of the art of balancing the many competing factors involved in both the warhead design—safety of all kinds, yield, size, shape, weight, mass distribution, cost and producibility, and use of nuclear materials—and the design of the overall reentry system," says Rich Wagner, former B Division leader and former assistant to the Secretary of Defense for Atomic Energy. "He taught this art to the people who worked for and with him at the labs, in the Navy, and in the Air Force. Seymour's mastery of how to strike difficult and subtle performance-related balances, and his ability to train others in the art, are the basis for the nation's ability today (over a quarter of a century after the last U.S. nuclear test) to sustain the stockpile without nuclear testing."

Personally, Sack was unique in that he understood how to help others maximize their potential to achieve needed results—he was tactful and thoughtful in interactions with people and could talk to machinists or senators with ease and mutual understanding.

"Seymour would constantly be reading about other fields, which enabled his ability to communicate with all specialists to tell them what he needed for his nuclear weapons designs," says Cal Wood, an LLNL experimentalist who worked closely with Sack. "He guided research in areas like high explosives chemistry because he could speak to the chemists in their language, direct them on the types of experiments needed, and how to get the results he needed. This was the same for many diverse fields."

Seymour honored with Enrico Fermi Award

Seymour Sack was awarded the 2003 Enrico Fermi Award for "his contributions to the national security of the United States in his work assuring the reliability of nuclear weapons and thus deterring war between the superpowers," reads the award citation. Sack received a gold medal and a citation signed by President George W. Bush and Secretary of Energy Spencer Abraham.

The Enrico Fermi Award is a Presidential award—one of the oldest and most prestigious science and technology awards given by the U.S. government. The award dates back to 1956 and honors physicist Enrico Fermi, who in December 1942 led scientists at the University of Chicago in achieving the first self-sustained, controlled nuclear reaction. It recognizes scientists of international stature for lifetimes of exceptional achievement in the development, use, or production of energy—broadly defined to include nuclear, atomic, molecular, and particle interactions and effects. The range and depth of Sack's accomplishments make him the preeminent designer of nuclear weapons in the history of the U.S.

"Seymour's influence on the U.S. nuclear deterrent is immense," writes Charles F. McMillan, former program leader in the Defense and Nuclear Technologies Directorate, in the Fermi award announcement. "His fingerprints are on all of the primaries in today's modern stockpile. His most enduring legacy, however, resides within LLNL's own nuclear design community. He continue[d] to convey to those among us who came after him a deep commitment to simple and efficient ideas."[4]

Even during his retirement, Sack continued to speak frankly on many of the issues facing the nation during the current decade of stewardship without nuclear testing. His personal and technical integrity led him to consistently debunk the arguments of those who call for a return to nuclear testing. He had, on numerous occasions, pointed out that there are currently no compelling technical reasons for nuclear testing.[2] His opposition to nuclear testing was derived from his knowledge of the state of current weapon designs and his deep understanding of the issues facing stewardship.[4,5]

(left) Seymour pictured with the Enrico Fermi Award medal. (right) The back of the medal is pictured with the award justification.

CONTRIBUTIONS TO NUCLEAR WEAPONS DESIGN

Father of the Modern Primary

PIONEERING COMPUTATIONAL MODELS

Lawrence Livermore's history is inexorably tied to the evolution of supercomputers and computational models. Even before the Laboratory opened, founders E. O. Lawrence and Edward Teller recognized that computers were needed to better calculate the thermonuclear explosions for the nuclear weapons the "Rad Lab" in Livermore was destined to design. LLNL's first big procurement was a state-of-the-art computer, the room-sized Univac-1, which had 5,600 vacuum tubes and 9 kilobytes of memory and ran at a speed of 1,000 floating-point operations per second (flops).

Designing nuclear weapons and predicting their behavior has always been a difficult technical and scientific challenge. In a thermonuclear explosion, matter is accelerated to millions of kilometers per hour while experiencing densities and temperatures found only in stars. In addition, weapon designers needed to identify and understand the important physical properties of matter under these exotic conditions. With little experimental data available, Livermore's designers turned to computers to simulate and visualize the processes and the physics of nuclear weapons.

The Univac-1 was LLNL's first large procurement. Although highly accurate, the Univac was cantankerous, breaking down two or three times a day. Early workers regarded it as an "oversized toaster."

Sack joined the Laboratory in 1955, at a time when nuclear weapons design relied heavily upon testing and experimental results. A design might be tested hundreds of times to ensure it would work. However, no fundamental, highly detailed calculations were done to ensure the designs were the best they could be.

Sack contributed to the development of 2D hydrodynamics codes and in the early 1960s applied them to the design of the safe, modern primary deployed in the Polaris warhead. He also developed one-point safety calculational techniques, systematics, and 2D Lagrange hydrodynamics codes. Using computational models to improve warhead design became a game changer for the nation and would become increasingly influential for stockpile stewardship.

"He was the developer of the hydrodynamic codes that became the basic design tools for modeling the implosion process, and he also developed the calculational techniques and systematics for one-point safety analysis," says former LLNL director George Miller.[6]

Sack designed primaries for the first bombs small enough to be deployed on the Poseidon submarine-launched ballistic missile and the Minuteman intercontinental ballistic missile. These designs were prototypes for the warheads developed by Los Alamos and Lawrence Livermore.

In the 1990s, with the cessation of underground nuclear testing, advanced computational models figured prominently in plans for stockpile stewardship, helping scientists predict the behavior of the aging nuclear stockpile to better assess its safety, reliability, and security.[7]

MIRVS—MULTIPLE WARHEADS INCREASE MISSILE EFFECTIVENESS

In 1970, the United States introduced a new capability that dramatically increased the effectiveness of its land- and sea-based strategic missile forces. This capability, called multiple independently targeted reentry vehicles (MIRVs), deploys multiple warheads on one missile and allows each missile to attack multiple targets within a large "footprint." This provides considerable flexibility in targeting. "Although this basic idea appeared achievable at the time, every aspect of the overall system—the small size, high yield-to-weight warheads, the reentry body and its dynamics and accuracy, and the maneuvering 'bus' that carried and released the multiple reentry vehicles—needed to be worked out and integrated in detail, and proven in concert," says Wagner.

MIRVs are also more cost-effective because they leveraged the large costs of missile silos and submarines. Sack led the efforts to design warheads with the MIRV concept for the

Polaris, A Strategic Breakthrough

Polaris is a highly efficient deterrent system in which 16 compact missiles would be placed vertically aboard a submarine for launch on demand. Meeting the Polaris challenge has often been described as Livermore's coming of age. However, a moratorium on nuclear weapons testing went into effect during its development on November 1, 1958, and lasted until September 1961. Although the moratorium barred further testing of the Polaris warhead, deployment proceeded.[8]

Polaris designers trusted their work despite changes from the designs field-tested before the moratorium and the implementation of substantial warhead upgrades. A major factor in promoting this trust was computational modeling of the extremely complex physical phenomena involved in nuclear explosions. Stimulated by their concern to understand the physics, warhead designers devised increasingly complex computer codes to model the physical behavior of nuclear weapons. That required state-of-the-art computers and computational simulations. Widening efforts to understand complex phenomena through experiment and computer modeling became a Laboratory hallmark.[8]

Sack made important contributions to the design of the W58 primary for the Polaris A-3, which included executing the first detailed calculations of certain critical features of the imploded configuration. His code work, coupled with steady improvements in computational technology, allowed quick turnaround calculations (literally overnight) that became the standard for primary design and dramatically improved the confidence in pushing the design space for advanced primaries.[9]

This missile replaced the earlier A-1 and A-2 models in the U.S. Navy and also equipped the British Polaris force. The A-3 had a range extended to 2,500 nautical miles, multiple reentry bodies, and the new W58 warhead.[10]

Polaris A-3 was the third and last version of the U.S. Navy's first generation submarine-launched ballistic missile. It was deployed between 1964 and 1981. Sixteen were carried on each Polaris submarine. The A-3 had a range of 2,500 nautical miles and carried three W58 thermonuclear warheads, and represented a significant advancement in warhead technology.[10]

Minuteman III intercontinental ballistic missile and the Poseidon C-3 submarine-launched ballistic missile.

The W62 warhead for Minuteman III (deployed in April 1970) and the W68 warhead for C-3 (deployed in June 1970) pushed the envelope of the yield-to-weight ratio, key to the MIRV concept, which was successful in part due to Sack's contributions that enabled the small, compact primary design. "That this succeeded was the work of many people, but Seymour was, I believe, first among them, not only because the warhead designs were important and difficult, but also because Seymour's influence and his approach to integrating complicated things extended well beyond the warhead, especially for the first MIRVs for Minuteman and Poseidon, which set the pattern for the later systems," says Wagner.

They were also the first designs to include a comprehensive set of hardening features for protection against antiballistic missile (ABM) defenses. The warheads were the product of an extremely fruitful period in weapons development at the Laboratory during the 1960s.

The MIRV concept resulted from the convergence of missile technology improvements, concerns about Soviet work on ABM systems, and the desire for improved accuracy. Early in the development of Minuteman III, it became clear that a liquid-fueled fourth stage was needed for higher delivery accuracy. Further consideration led to the concept of using additional fuel in the fourth stage to independently target multiple reentry vehicles and penetration aids. Meanwhile, the ability of missile systems to deploy individual satellites through use of a post-boost control system had been demonstrated in the U.S. space program in October 1963. In December 1964, Secretary of Defense Robert McNamara approved development of a MIRV system for Minuteman III. By early 1965, the Navy's Strategic Systems Project Office had developed baseline design requirements for the C-3 missile that would include the MIRV capability.

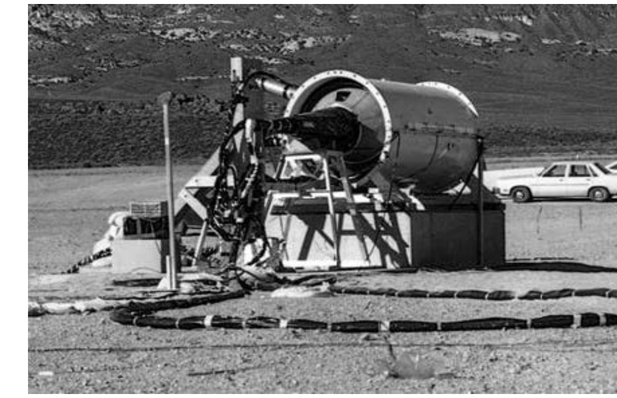
Lawrence Livermore received the assignment for both systems, and each program faced significant design challenges. The requirement to put up to 14 reentry bodies on the relatively small C-3 missile was very stressing. The W68 (in the Mk3 reentry body) was the smallest strategic warhead ever deployed by the U.S.

The yield of the W62 had to be sufficient for attacking hardened missile silos, and the design of the Mk12 reentry vehicle placed stringent volume limitations on the warhead to achieve the required accuracy. In addition, both warheads included special hardening features intended to improve survivability when penetrating a threat ABM system. These features were developed with the aid of an extensive series of "exposure" nuclear tests conducted in conjunction with the Defense Nuclear Agency. Sack provided important input to the design of the experiments and the interpretation of the data collected.

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

When the first MIRV systems were deployed more than 30 years ago, they marked the end to a chapter in which Lawrence Livermore and the military redefined the strategic missile posture of the U.S.

Thanks to Sack, the W62 and W68 represented such a dramatic advance in the state of nuclear weapons design that all subsequent missile system warheads have incorporated many of their key elements. Their extensive development programs, conducted in close coordination with the U.S. Air Force and the U.S. Navy and their contractors, were a model for all subsequent generations of delivery-system design teams.[11]



A mock W87 warhead with insensitive high explosive in a Mk21 reentry vehicle is mounted on simulated upper stages of the Peacekeeper missile (in a canister) in preparation for an explosive test to determine accident environments and warhead response.

TATB MAKES NUCLEAR WEAPONS SAFER

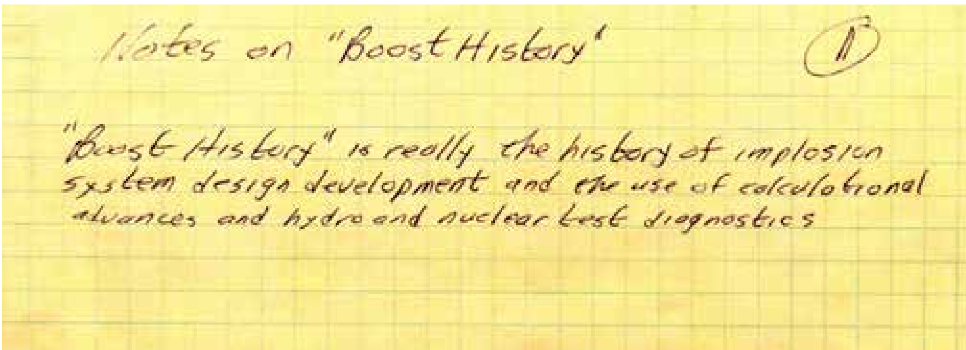
In 1975, Laboratory researchers published their first report on investigations of an insensitive high explosive, TATB (triamino-trinitrobenzene). Further work to characterize the material and find improved ways of producing it has led to widespread use of insensitive high explosive in nuclear weapons. Use of insensitive high explosive is one of the many important advances made over the past five decades to improve the safety and security of nuclear weapons. Its development is a demonstration of the expertise in energetic materials that resides at the nation's nuclear weapons laboratories.

First synthesized in the 19th century, TATB qualifies as an insensitive high explosive because of its inherent insensitivity to shock. The material is virtually invulnerable to significant energy release in plane crashes, fires, or explosions, or from deliberate attack with small-arms fire. In fact, TATB is so stable that researchers had to discover how to reliably initiate an explosion of the material. They also had to find a ready and affordable way to produce the material. Building on advances made at both nuclear design laboratories, Los Alamos researchers made a key improvement in 1967 by finding a way to prepare TATB as a molded, plastic-bonded explosive at close to theoretically maximum density. While Los Alamos was first to develop the idea of using insensitive high explosive in primary design, they encountered difficulties successfully incorporating insensitive high explosive into a nuclear weapon and had declared it too hard to use in their designs.

A team led by Sack made design advances that enabled TATB's reliable use in nuclear weapons. The first nuclear weapon systems to include TATB were variants of the B61 bomb and B83 strategic bomb. The W87 intercontinental ballistic missile warhead was the first design to use TATB for the explosive detonators as well as for the main explosive charge, further enhancing safety.[12]

MARGINS AND ROBUSTNESS

Sack emphasized the importance of margins and robustness in the design of reliable primaries. He wrote a lengthy article about robustness and another about margins in 1988.[13] He identified robustness as a warhead's ability to function despite unknown harsh conditions or circumstances. "I will define robust as capable of maintaining functionality in spite of known variations and qualitatively guesstimated unknown variations in weapon status and operations conditions," Sack wrote. "As applied to primaries, these include boost gas aging, overinitiation, operating temperature range, expected hostile environments, fabrication variations... and the unknown (chemical aging effects or whatever)."


Notes on "Boost History" (1)

"Boost History" is really the history of implosion system design development and the use of calculational advances and hydro and nuclear test diagnostics

Sack was a key contributor to the study of boost in nuclear weapons, which is the use of a small amount of fusion fuel to increase the rate and yield of a fission reaction. The use of boost allows for the high yield-to-weight ratio and miniaturization option that modern nuclear weapons designs rely upon. Pictured is an excerpt from one of Sack's handwritten notes regarding boost.[13]

Sack's early identification of the need for margins and robustness to be considered in nuclear weapons design transformed the way LLNL and other national laboratories maintain the U.S.'s nuclear weapons stockpile. Although the engineering and physics performance of the warheads could be tested in a wide range of conditions applicable to the stockpile-to-target sequence, they could not be tested in all conditions. Sack conveyed his methodology in using analytical tools to gain a full understanding of weapon performance. "In evaluating new or modified primaries, we have an impressive array of tools, computational and hydro-experimental available," Sack wrote. "The full suite of tools should be required for any statement of expected performance."

The importance of margins and robustness was later formalized by Michael Anastasio. When he was the principal associate director of the Weapons and Complex Integration Directorate at LLNL, Anastasio established the methodology of the quantification of margins and uncertainties (QMU) as part of the weapons design process. "Sack certainly inspired the ideas that led to QMU," says Anastasio.

> "[Seymour] inspired and trained many young scientists by selflessly sharing his energy and intellectual talent. I was fortunate enough to be one of those lucky scientists, and for this I am grateful."
>
> —Bruce Goodwin, former principal associate director, WCI Directorate[4]

SEYMOUR AS AN EDUCATOR

> "One might think that such a giant might frighten off those clumsily groping to follow in his footsteps. Yet he is generous with his time, kind in his reproaches, and a gentle nagger who will suffer us fools, as long as he perceives some hope in our redemption."
>
> —Kris Winer, former LLNL employee and Sack's mentee[4]

Inspiring the Next Generation of Weapons Designers

Sack assembled and led a small, high-functioning primary physics team who designed and fielded the majority of the modern stockpile for which LLNL was responsible. On his team, Cal Wood executed many of the hydrotests and nuclear tests, Leon Keller designed the most optimized primaries during the nuclear testing era, and Gary Carlson wrote the state-of-the-art simulation codes. This team designed and fielded the B83, W84, W87, and numerous primary physics experiments. Anastasio, Goodwin, and Cynthia Nitta joined the team in the 1980s and advanced the understanding of boost physics and the QMU methodology for the stockpile.

Following his retirement in 1990, Sack returned to Lawrence Livermore and remained active in weapons design and policy for the next two decades until his passing in 2011. During this time, he largely focused on mentoring young scientists and passing along his wealth of knowledge.

Sack also documented his knowledge by writing many technical papers, participating in interviews, and creating valuable documents. His legacy is firmly entrenched with his seminal documents on subjects such as a vault tour guide for docents, Livermore fission weapon design, boost history, marginality, and robustness. Of course his documented work on the Livermore warheads, both proposed and accepted into the stockpile, form a permanent legacy that will be essential reading for all in the future weapon programs.

Have you had a "Sack Lunch"?

Seymour would often stop in and have extended technical chats with his engineering colleagues and group members at the time when most workers' schedules were open—at lunch. This became such a common, endearing occurrence that colleagues would often ask each other, "Have you had your Sack lunch?"

LEGACY & IMPACT

"Seymour was quite fond of describing B Division and the whole Weapons Program as a 'service organization.' When impatient about not getting the cooperation necessary he would feel the need to passionately declare, 'You're a service organization, so serve!' Underneath the tough exterior that most people saw was physical courage and a sense of service."

—Leon Keller, former LLNL primary designer

"I started out doing nuclear weapons design at LANL and worked with the smartest designer there. He almost immediately told me about Seymour Sack and how he was the master and greatest intellect in design. After working there for about three years, my LANL boss told me that if I wanted to advance my skills, I should quietly try to get hired at LLNL and see if I could get into Seymour Sack's group! That is one amazing recommendation! I got lucky and did get hired into Seymour's group and have been a happy designer ever since."

—Bruce Goodwin, former primary designer under Seymour, former principal associate director, WCI Directorate, and currently senior laboratory fellow

"Of the thousands of lessons I learned by working with Seymour, one experience stands out in my memory as representing how humble Seymour was, even though he knew more about nuclear weapons than almost anyone else: when I had a tight deadline early in my LLNL career, he surprised me by sitting down to help me type in contours into the computer model from drawings even when he had many other things to do. He was never above doing the daily grunge work or whatever it took to get the job done. This left a deep and lasting impression on me about how this great man approached our weapons program mission with the mindset of service to others."

—Cynthia Nitta, former primary designer and associate program director for Stockpile Technologies and Certification Methodologies

"Seymour always had the best interest of the greater good in mind when it came to his work, whether others knew it or not. There's almost no limit to the amount of good a person can do, as long as he doesn't care who gets the credit. Seymour fully embodied this mentality."

—Cal Wood, former LLNL lead design physicist

"What I believe defined Seymour was his great interest in the detail of his projects. He mentally kept track of his programs and was always ready to discuss how things were going and to offer support. I always enjoyed working with him because he could grasp a problem quickly and understand how you were attacking it; he was not afraid to provide input if he thought that you weren't on the right track."

—Doug Kautz, LANL engineer

"I was frequently in contact with Seymour from 1987 until about a year before his death. Seymour used me as an informal contact between the designer communities in Livermore and Los Alamos. Seymour was a giant in the weapons design community and his advice was valued greatly. His contributions to the national defense program are voluminous but are documented only in classified literature. It was a valued opportunity and pleasure to work with Seymour. He added to my own work product in many ways."

—John Kammerdiener, former LANL secondary and primary designer

"Although Seymour had retired by the time I started, he came in regularly and always took the time to encourage new designers and tirelessly impart his extensive knowledge. More importantly, he conveyed the values and work ethics of being a designer. There were several major principles I learned from Seymour. 1) Learn everything about the system, from how it is deployed down to every detail of the design, including all aspects of weapon physics and how it is engineered and manufactured. 2) Know all the details, but figure out what is important and work on that. 3) Teamwork is essential to make the design work. Collaborate with your colleagues—physicists, engineers, chemists, and experimentalists—and your customers. 4) Take personal responsibility as the designer for both the success and failure of the warhead design."

— Juliana Hsu, primary designer, distinguished member of the technical staff, and deputy program director for Weapon Physics and Design, WCI

EPILOGUE

Seymour Sack leaves not only a legacy of what has been mentioned in this document, but also his vision continues to drive the need for archiving of and coherent access to Lawrence Livermore's rich historical data. Sack knew that if we could adequately capture and catalogue Lawrence Livermore's data, it could be an invaluable resource throughout time to help future generations of scientists better understand important tools, experiments, and the nuclear weapons stockpile. For this reason, it is imperative that LLNL and other national laboratories not only continue to capture new data as it is created, but also organize it into the archives so it is an available tool for years to come.

> "You want to end up with a very reliable weapon. It does not matter that the tests were done 25 years ago."
>
> —Seymour Sack on nuclear testing in an interview with the *Los Angeles Times* in 2007[14]

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> Seymour taught the arts of balance and deep understanding to those who worked for and with him at the Lab and elsewhere. His lessons in these arts turned out to be life lessons for many of those people, some of whom later applied them in different and broader regimes. Seymour could be pretty crusty, but I don't remember a single case where his crustiness was gratuitous; it was always to achieve an effect that he thought was necessary. He would go outside channels when he thought it was needed."
>
> —Rich Wagner, former B Division leader and former assistant to the Secretary of Defense for Atomic Energy

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