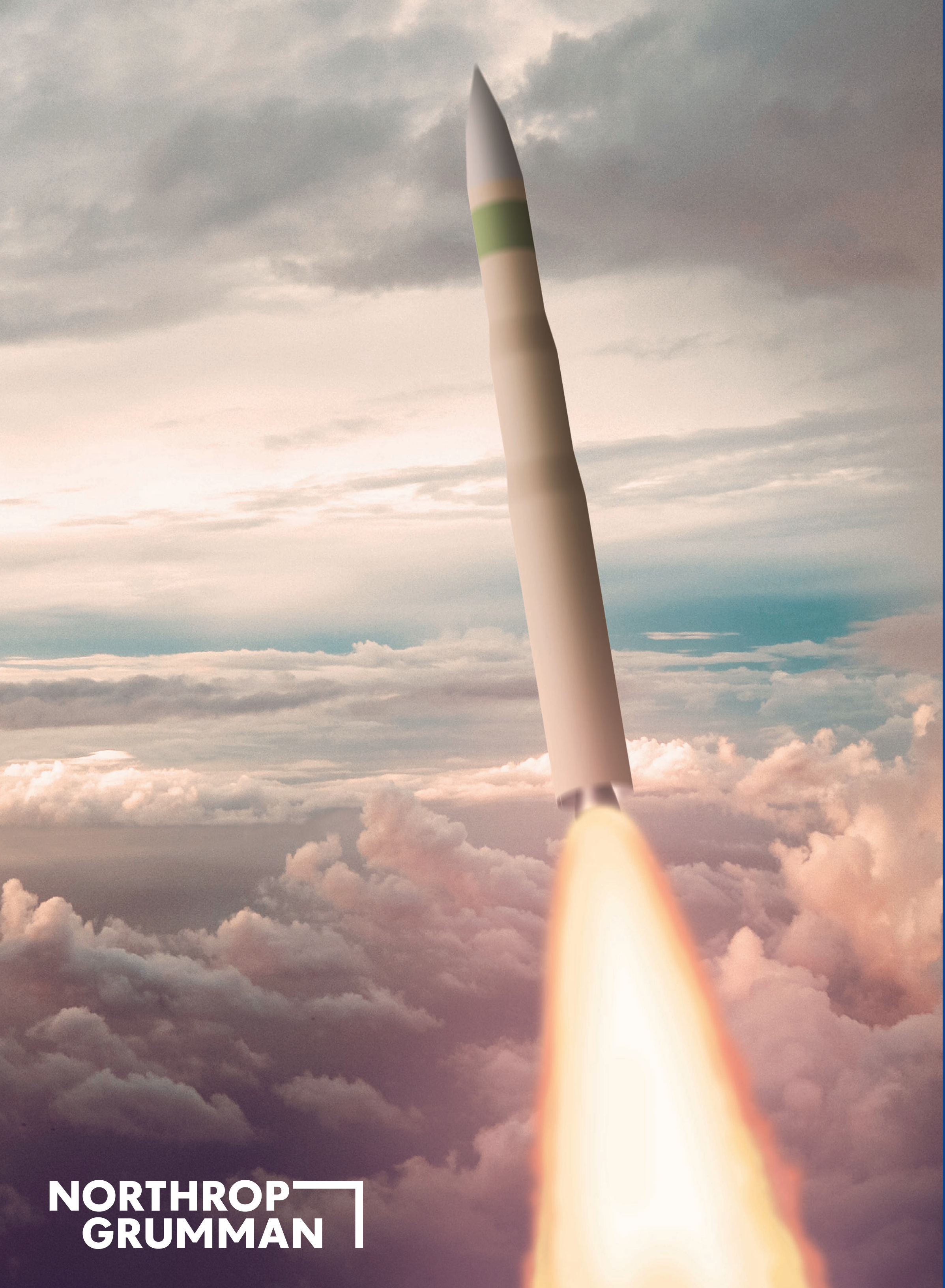


ADVANCING OUR LEGACY

NORTHROP GRUMMAN'S HISTORY WITH THE ICBM SYSTEM

Origins

At the end of World War II, the United States had a nuclear monopoly. But following the Soviet Union's successful nuclear test in 1948, the U.S. began pursuing new capabilities that would allow it to promptly respond to a Soviet nuclear strike – thereby deterring one.

Intercontinental Ballistic Missiles (ICBMs) solved two critical dilemmas posed by the Soviet threat: speed to target and prompt response. With the advent of solid-fuel rockets, the U.S. had a land-based nuclear force that was able to sustain a ready alert status and reach targets around the globe.

Today, our nation deters its adversaries – and assures its allies – through the complementary systems of the U.S. nuclear triad. And, as our nuclear weapons have evolved, so too has the industrial base that builds and sustains them.

Through Northrop Grumman's heritage companies - early partners like Ramo-Wooldridge (later TRW), Thiokol and Hercules - as well as relative relative newcomer Orbital ATK, the company has supported, sustained and modernized the Air Force's ICBM Systems since the 1950's, work that continues today.

Additionally, Northrop Grumman's heritage as one of the earliest developers of solid rocket motor technology is still evident; the company is currently supporting the operational Minuteman III ICBMs for the U.S. Air Force as well as retired Minuteman and Peacekeeper motors. Northrop Grumman also produces the motors for the U.S. Navy's Trident D-5 missile as well as interceptor and target vehicles for missile defense. In partnership with our nation's military and its allies, Northrop Grumman has been delivering strategic missile capabilities that promote strategic stability for more than 60 years.

Origins of the ICBM

As the United States raced to develop new military technologies in the 1950s, a number of technical and geo-strategic shifts accelerated the pursuit of ICBMs. But perhaps the most important catalyst was the arrival of two influential Air Force leaders.

First, in February 1953, Trevor Gardner became Special Assistant to the Secretary of the Air Force for Research and Development. Supported by then-retired Air Force legend Lt. Gen. James Doolittle, Gardner believed ICBMs offered the U.S. a major nuclear advantage that would eclipse existing Soviet capabilities.

Second, in March of that year, Col. Bernard Schriever was named Assistant for Development Planning under the Air Force Deputy Chief of Staff for Development, and would soon be promoted to Brigadier General. A leading member of the service's nascent research and development community, and a protégé of Hap Arnold, he came to be known as the "Father of the ICBM system."

Schriever and Gardner quickly joined forces to promote emerging ICBM technology within the Air Force and convened a subcommittee of the Air Force Scientific Advisory Board's (SAB) Nuclear Weapons Panel to validate their approach. To make the case for ICBM development, Gardner and Schriever seized upon recent advances in thermonuclear weapons. While these (smaller) warheads were not the only missing ingredient, they provided a powerful catalyst to accelerate ICBM program development.

By October, Gardner and Schriever's subcommittee study was complete. The final report argued that the size, shape, and yield of thermonuclear weapons were perfectly suited to an ICBM, and that such weapons could have a meaningful impact on the incipient Atlas long-range missile program that was already underway.

With this clear endorsement, the stage was set for more ambitious ICBM development, and an emerging industry perfectly suited to take on the challenge.

Top left: Gen. Bernard Schriever; **Bottom right:** Legacy ICBMs on display. (U.S. Air Force photo)

Lonnquest, John C. and David F. Winkler. "To Defend and Deter: The Legacy of the United States Cold War Missile Program." Department of Defense Legacy Resource Management Program: 1996. Pages 34-37.

Origins of Innovation

Air Force and Industry Usher in New Class of Weapon System

As the Air Force prepared to move forward with a new class of weapons, it called on a new kind of industry partner that was taking shape in this era. Over the next 60 years, names like Ramo-Wooldridge (later TRW), Thiokol, Hercules, ATK, and later Orbital Sciences would emerge to play critical roles in the design, integration, production, and sustainment of Air Force missile systems. These companies exist today as Northrop Grumman, where thousands of engineers and scientists pursue innovations that ensure the viability of our nation's strategic missiles and their role as a critical deterrent force.

Time Magazine cover from April 1957 with Dean Wooldridge and Simon Ramo, right.

Ramo-Wooldridge Corporation

Simon Ramo and Dean Wooldridge founded Ramo-Wooldridge Corporation in 1953. Previously with Hughes Aircraft, they earned acclaim for their work on the Falcon missile system, the Air Force's first operational air-to-air guided missile. Ramo-Wooldridge became TRW in the 1960's and was later acquired by Northrop Grumman.

From the beginning, Ramo-Wooldridge played a crucial role in the development of the U.S. strategic missile force, serving as its first "systems engineering and technical direction" (SE/TD) contractor on the Atlas program. This unique partnership would endure for every future Air Force ballistic missile program ever fielded: Thor; Titan I and II; Minuteman I, II, and III; Peacekeeper; and Small ICBM.

The resulting processes and insights as well as the technological advancements in designing and producing large strategic missiles embody Northrop Grumman's ICBM support to this day.

Thiokol

Starting as a rubber and related chemicals company in 1929, Thiokol turned to rockets and missile propulsion and in 1948, static tested its first solid rocket motor at Elkton, Maryland. The company also produced the TX-18 Falcon missile, the world's first solid-fuel missile. In 1956, Thiokol purchased extensive land near Promontory, Utah to manufacture and static test solid-fuel rocket motors, including the first stage of the Air Force's new ICBM – Minuteman. For more than 50 years, the company would continue providing motor stages for each new generation of Minuteman ICBMs. The company was purchased by ATK in 2001.

Dyer, Davis. "Necessity as the Mother of Convention: Developing the ICBM, 1954-1958." Journal of Business and Economic History. 22:1 (1993). Pages 196-197.

Kennedy, W.S., S.M. Kovacic, and E.C. Rea. "Solid Rocket History at TRW Ballistic Missiles Division." American Institute of Aeronautics and Astronautics: 1992. Page 4 and Page 202.

Hanson, Tom and Kim R. Burningham. "Davis County On the Move." 2016. Page 170 - 172

Sauer, Dennis T. "Hercules/ATK History, (1913-2014)." (2014).

Sutton, E.S. "From Polymers to Propellants to Rockets – A History of Thiokol." American Institute of Aeronautics and Astronautics. 1999 (2929). Page 1.

Hercules

Founded in 1912, Hercules Powder Company was a chemical and munitions company that, in 1958 began to diversify into the production of large solid-fuel rocket motors, becoming a primary producer for the Defense Department and NASA. Hercules produced the third-stage motor for the three-stage solid-fuel Minuteman I and continued that work for Minuteman II from its Bacchus facility in Utah. In addition to its ongoing work for the U.S. Air Force, Hercules also supported strategic missile production for the U.S. Navy, producing solid-fuel rocket motors for the two-stage Polaris A2 and A3 system of intermediate-range ballistic missiles. In a joint venture with Thiokol, Hercules also produced all three solid rocket stages of the three-stage Trident I (C4) for the U.S. Navy. Working together, Hercules and Thiokol also produced the Trident II (D5), a three-stage solid propellant missile. Deployed in 1990 as the U.S.'s strategic seaborne deterrent, the Trident D5LE (life-extension) version will remain in service until 2042. Hercules was purchased by ATK in 1995.

ATK

ATK was launched as an independent company in 1990. Based on its acquisitions of Hercules and Thiokol, ATK became known for producing propulsion systems for space exploration, commercial launch vehicles and strategic and missile defense uses. The company was headquartered in Magna, Utah and was later acquired by Orbital Sciences Corporation in 2015, becoming Orbital ATK.

Orbital Sciences

Created in 1982, Orbital Sciences specialized in the design, manufacture and launch of small- and medium- class space and rocket systems for commercial, military and other government customers. Following the end of the Cold War, Orbital developed the Minotaur family of expendable launch vehicles (or rockets) that use deactivated Peacekeeper assets and is the primary producer of interceptors and target vehicles for the U.S. Missile Defense Agency. Orbital ATK was purchased by Northrop Grumman in 2018.

Hanson, Tom and Kim R. Burningham. "Davis County On the Move." 2016. Page 170 - 172

Sauer, Dennis T. "Hercules/ATK History, (1913-2014)." (2014).

Sutton, E.S. "From Polymers to Propellants to Rockets – A History of Thiokol." American Institute of Aeronautics and Astronautics. 1999 (2929). Page 1.

Origins of an Enduring Partnership

A Unique Relationship

On the heels of the Air Force Scientific Advisory Board's (SAB) Nuclear Weapons Panel subcommittee study in 1953, Gardner and Schriever recommended a comprehensive review of the Air Force's existing long-range missile programs — Snark, Navaho, and Atlas.

In 1954, Gardner assembled eleven leading scientists and engineers from academia and industry – including Ramo and Wooldridge - to participate in the Strategic Missiles Evaluation Committee, better known by its codename: the Teapot Committee.

General Bernard Schriever and Si Ramo. (U.S. Air Force photo)

The committee's recommendation was to accelerate the Atlas project. Gen. Schriever promptly implemented next steps and saw Ramo-Wooldridge as "made to order for the job." Schriever's path forward required a "unique setup" and a close partnership with the firm, whose employees understood both the key technical requirements of the ICBM system and the personal views of Air Force leaders, while also bringing an array of talents and skills that could not be found elsewhere. In short, Ramo-Wooldridge combined the system engineering and design capabilities of an industrial contractor with the research strengths of an academic organization.

Ramo-Wooldridge accepted the role of SE/TD contractor, making them an integral part of the service's overall design and integration effort. As described by Schriever, Ramo-Wooldridge would, in effect, become "part of the Air Force family for this project." He used them to "create specifications, oversee development, and coordinate between the Air Force and numerous sub-contractors." In doing so, it would provide crucial support to the Air Force and became its indispensable partner as the service launched into a new era of missile development and production.

Dyer, Davis. "Necessity as the Mother of Convention: Developing the ICBM, 1954-1958." Journal of Business and Economic History. 22:1 (1993). Pages 196-197 and Page 202.

Kennedy, W.S., S.M. Kovacic, and E.C. Rea. "Solid Rocket History at TRW Ballistic Missiles Division." American Institute of Aeronautics and Astronautics: 1992. Page 4.

A Burgeoning ICBM Capability

Atlas missile being tested for use as ICBMs.

Atlas & Titan

The development and integration of the first ICBM system involved four overlapping phases, defined in collaboration between Ramo-Wooldridge and Schriever's Western Development Division (WDD). By early 1955, the basic design of Atlas was set, and the Air Force was prepared to award contracts for the missile's structure and major subsystems. While Ramo-Wooldridge played a crucial role coordinating the work of the many contractors, its most important contribution concerned how to speed up the program.

Such improvements, which are estimated to have saved more than a year of development time and a quarter of the missile's total cost, did much to confirm Ramo-Wooldridge's bona fides as the SE/TD partner to the Air Force. Ramo-Wooldridge supervised the development, creation, and testing of key system components. In particular, the company instituted a rigorous hierarchy of checks to ensure that actual flight testing was only conducted after exhaustive ground testing.

Meanwhile, to mitigate the risks associated with the nascent Atlas design, the Air Force simultaneously pursued development of the Titan missiles. Even as the first Titan I missiles – themselves a major improvement over the first-generation Atlas – were rolling off the production line, the Air Force was searching for an improved system to overcome Titan I's two major weaknesses associated with its cryogenic propellant and guidance systems. Titan II corrected these two major deficiencies, and Ramo-Wooldridge provided the technical and managerial direction for these system innovations.

Titan missile used by the U.S. Air Force. (U.S. Air Force photo)

While Atlas and Titan – the first two American ICBMS ever fielded - were marvels of engineering, they were also liquid-fueled. Meeting the range and payload requirements of Air Force planners required a significant amount of this propellant. Because of its combustible nature, early missiles could not be stored with their fuel, but had to be fueled on the launch pad, limiting their readiness and increasing their vulnerability.

The real payoffs of the ICBM age were soon to come as innovations in solid rocket motors by companies like Thiokol and Hercules drove the design and development of a new system.

Dyer, Davis. "Necessity as the Mother of Convention: Developing the ICBM, 1954-1958." Journal of Business and Economic History. 22:1 (1993). Pages 196-197 and Page 202.

Lonnquest, John C. and David F. Winkler. "To Defend and Deter: The Legacy of the United States Cold War Missile Program." Department of Defense Legacy Resource Management Program: 1996. Pages 34-37.

Solid Motor Technology Changes the Game

Minuteman

Minuteman I Missile. (U.S. Air Force photo)

Out of necessity, the first generation of ballistic missiles (Atlas, Titan, and the intermediate ballistic missile, Thor) were liquid-propellant engines. By 1957, the Air Force and industry seemed to be on the verge of a breakthrough: the combined trends of reduced weight, increased warhead yield, improved accuracy, and solid rocket motor development argued in favor of a new, solid-fuel ICBM.

Ramo-Wooldridge, Thiokol, and Hercules were intimately involved with many of these important advancements, especially those associated with re-entry vehicle technology and solid rocket motor development.

Computer studies by Ramo-Wooldridge provided crucial evidence demonstrating the feasibility of solid-propellant rockets and outlining suggestions for new approaches to meet their unique technical challenges. These studies were seized upon by Air Force Col. Edward Hall, who had been researching solid-propellants at the Wright-Patterson Air Force Base Propulsion Laboratory.

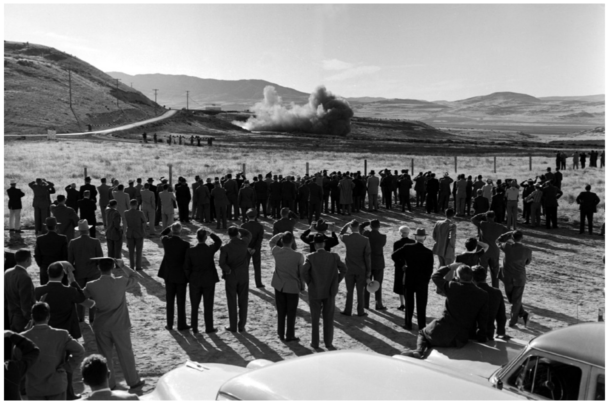
Working together, Hall and a special Ramo-Wooldridge study group developed the preliminary design and specifications for a solid-propellant ICBM. These initial studies by the firm proved instrumental to advancing solid-propellant research.

Meanwhile, Thiokol and Hercules – leaders in large rocket motor technology - had constructed several new solid-propellant facilities across Utah. In 1957, Thiokol conducted the first static test fire of a Minuteman stage one at its Promontory, Utah plant, ushering-in a new generation of ICBMs that would depend upon solid fuel. The companies would go on to produce stage one (Thiokol) and stage three (Hercules) for Minuteman I and II and stages one and three (Thiokol) for Minuteman III.

Ramo-Wooldridge was intimately involved, as well, in rocket motor case design and fracture mechanics studies. Its investigations into heat treatment and fracture toughness of high-strength materials provided the critical data and design direction needed to assess the specific tradeoff between an increase in strength and a decrease in capability. In addition, Hercules contributed to these advancements with their early work developing and testing composite cases for Minuteman I stage three.

Thanks to these and other major advances, a solid-propellant, three-stage Minuteman I was successfully launched on its first full-flight test in February 1961 at Cape Canaveral. That the missile flew without incident - on its first complete attempt - is a testament to the remarkable technological progress and the effective managerial systems skills of this new era of leaders, Ramo-Wooldridge, Hercules, and Thiokol.

Kennedy, W.S., S.M. Kovacic, and E.C. Rea. “Solid Rocket History at TRW Ballistic Missiles Division.” American Institute of Aeronautics and Astronautics: 1992. Page 4.



Thiokol conducted the first static test fire of a Minuteman I stage in 1957.

Overall, the entire Minuteman system was far superior to Atlas, Titan, and Thor. It was so successful that the Air Force was able to retire all of its older generation missiles, other than Titan II, earlier than expected.

As the Cold War intensified, the first production Minuteman rolled off the assembly line in 1962 and was delivered to the Air Force a full year ahead of schedule. Three years later, Minuteman II entered service with an increased range, payload capacity and improved guidance system and in 1970, Minuteman III became operational. Throughout production, improvements were made to the ICBM's propellant, motor cases, nozzles, and thrust vector control systems to increase the missile's range and speed. When Minuteman production ended in the late 1970s, Northrop Grumman had manufactured more than 4,000 Minuteman motors.

For more than 40 years, these heritage Northrop Grumman companies continued to build, sustain and improve readiness for the Minuteman system until the company was selected to modernize the force in 1997.

Peacekeeper + Small ICBM

Despite the successful Minuteman III deployment, U.S. fears of Soviet strategic advances led to efforts to design two new missiles in the 1970s and 80s: the MX Peacekeeper, the largest missile to date carrying the most warheads; and the Small ICBM, a smaller missile and payload with mobile launch options.

As the Air Force matured its missile expertise, TRW transitioned to a Systems Engineering, Technical Assistance (SETA) contractor role, while Hercules and Thiokol would design and build advanced solid rocket motors for both missiles.

TRW effectively carried out its SETA duties on Peacekeeper, which Secretary of Defense Caspar Weinberger later labelled Peacekeeper the most successful ICBM program in Air Force history. Perhaps most importantly, TRW defined the sizing of the overall missile system and its various stages. Using computer modeling, the company developed a method to compare proposed designs and evaluate how they would affect key metrics like range and payload.

Peacekeeper Missile.

While Peacekeeper was eventually fielded in small numbers, the end of the Cold War terminated Small ICBM, and Peacekeeper was deactivated in 2002. The experience of developing and producing key elements of these missiles greatly contributed to the accumulated expertise within Northrop Grumman today.

Kennedy, W.S., S.M. Kovacic, and E.C. Rea. “Solid Rocket History at TRW Ballistic Missiles Division.” American Institute of Aeronautics and Astronautics: 1992. Page 4.

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Minuteman III Sustainment and Modernization

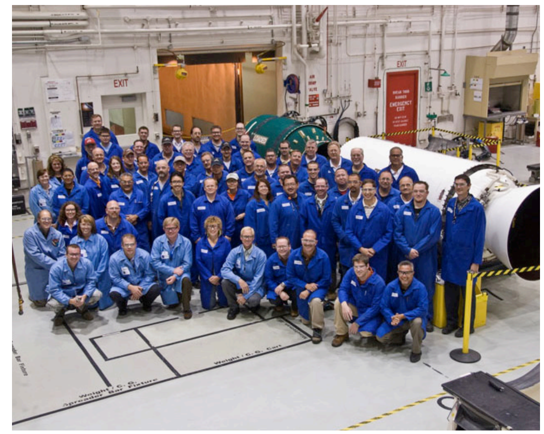
Over the last 20 years, the Air Force has modernized or engaged in service-life extension programs for the most critical elements of the ICBM system. Through these contracts, Northrop Grumman touched every element of the current force's systems, leading the efforts to upgrade or replace propulsion, guidance, structure, reentry vehicles, nuclear payloads, and ground infrastructure, gaining intimate knowledge of each component and interactions.

ICBM Prime Integration Team

ICBM Prime Integration Contract (IPIC)

One of the largest sustainment efforts to date was the ICBM Prime Integration Contract (IPIC). Here, the Air Force transitioned management of its ICBM program — now just Minuteman III missiles — to a team of subcontractors reporting to a single prime integrator. In 1997, the prime integrator role was awarded to then-TRW, bringing this expertise to Northrop Grumman and continuing its 60-year ICBM legacy.

As part of IPIC, ATK was delivering on the Propulsion Replacement Program (PRP) to extend the service life of the Minuteman missile. In this role, ATK went on to remanufacture approximately 1,800 Minuteman motors and deliver an astonishing 26 motors per month to the U.S. Air Force. ATK developed and qualified the stage one remanufacture process and later assumed responsibility for remanufacturing all three stages. In 2006, the PRP team earned the distinguished Brent Scowcroft Award for outstanding performance.



Minuteman crew at Bacchus commemorates shipment of the last Minuteman PRP motors.

At the peak of IPIC, hundreds of Northrop Grumman employees at more than ten U.S. locations were tasked to extend the missiles' service life to 2030. These indviduals provided essential program management, assessment, and engineering services to maintain and modernize the weapon system's readiness, reliability, availability, accuracy, and hardness. In 2010, Congress approved the low-rate production Solid Rocket Motor Warm Line (SRMWL) program to preserve critical defense asset manufacturing.

Northrop Grumman's leadership role on IPIC combined with its expertise in producing large, strategic missiles form the basis of an enduring legacy that is helping to maintain a safe and ready missile force today.

Kennedy, W.S., S.M. Kovacic, and E.C. Rea. "Solid Rocket History at TRW Ballistic Missiles Division." American Institute of Aeronautics and Astronautics: 1992. Page 4.

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Performing Today, Preparing for Tomorrow

Northrop Grumman continues working with the U.S. Air Force to perform on several ICBM sustainment activities that will keep our ICBM force viable through 2030. They include:

Ground Subsystems Support Contract (GSSC)

Northrop Grumman is providing program management support, engineering services and emergency response to the U.S. Air Force for the Minuteman III ICBM Ground Subsystems.

Propulsion Subsystem Support Contract (PSSC)

Northrop Grumman provides sustaining engineering, software maintenance, developmental engineering, production engineering and procurement for the Minuteman III system. This includes support for solid and liquid propulsion, flight controls, system ordnance, and flight batteries.

Rocket Systems Launch Program (RSLP)

Northrop Grumman is conducting aging surveillance and motor disposal efforts on Minuteman and Peacekeeper motors. These retired motors are used for a variety of purposes, including government launches of the Minotaur series of rockets, Missile Defense Agency missions, and launches for NASA.

Ground Based Strategic Deterrent (GBSD)

In September 2020, the U.S. Air Force selected Northrop Grumman to modernize the nation's aging Minuteman III ICBM system under the engineering and manufacturing development (EMD) phase of the GBSD program. This effort includes weapon system design, qualification, test and evaluation and nuclear certification. Upon successful completion of EMD, the Northrop Grumman-led nationwide team will begin producing and delivering a modern and fully integrated weapon system to meet the Air Force schedule of initial operational capability by 2029.

Unparalleled ICBM Workforce

From the early days of Ramo and Wooldridge, Thiokol and Hercules to today's IPIC and its follow-on contracts, Northrop Grumman has preserved and expanded core skills in its ICBM workforce and established critical missile manufacturing capabilities in the U.S. With more than 60 years of excellence in designing, developing, building and sustaining the nation's ICBM force, Northrop Grumman is advancing its legacy as a builder of the nation's most complex defense systems.

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