Chapter 18

Intercontinental Ballistic Missiles

Maj Jane Gibson, USAF; and MAJ Kenneth G. Kemmerly, USA

This chapter covers American nuclear ballistic missile systems: the land-based intercontinental ballistic missiles (ICBM) and the submarine-launched ballistic missiles (SLBM). These ballistic systems are designated space assets because the weapon system travels through space to its given target, though on a trajectory that does not achieve a full orbit. Air Force Space Command is responsible for the ICBM force but will soon be transferring that to Air Force Global Strike Command. The SLBMs are under the responsibility of the US Navy.

Origins of ICBMs

The first reference to the use of rockets dates back to 1232 when the Chinese defenders of K'aifung-fu used "fire arrows" against attacking Mongols. Progress in rocketry was slow, at best, for the next seven centuries.

The Germans began development of a missile arsenal during the 1930s at Kummersdorf and Peenemünde, with increased emphasis during World War II. These experiments resulted in the Vergeltsungswaffe Ein and Zwei (Revenge Weapons One and Two), or V-1 and V-2. While the V-1 was an early unmanned aircraft system, the V-2 was a 46-foot-long rocket that used alcohol and liquid oxygen as propellants. It reached an altitude of 50 to 60 miles, had a maximum range of 200 miles, and carried a one-ton warhead. The system's accuracy was 2.5 miles. The war ended before the results of research into longer-range (transatlantic) two-stage rockets, called the A-9 and A-10, could be used. These weapons might have been operational by 1948.[1]

ICBM Characteristics

The ballistic missile as a weapon is often compared to an artillery cannon and its ballistic projectile. Critical to the accuracy of an artillery projectile are its elevation and speed. Apart from atmospheric resistance, gravity is the only vital force operating on the projectile, causing a constant-acceleration fall to Earth. As the distance to the target increases, so must the elevation (angle of launch toward the target) or speed (muzzle velocity) of the projectile increase.

For the ballistic missile payload or reentry vehicle (RV) to reach the target, the missile must be aimed toward the desired impact point and given a specific speed and altitude. There is one point somewhere along the missile flight path at which a definite speed must be achieved. The flight control system is responsible for getting the missile to this point.

From the moment of liftoff, the missile must stabilize in its vertical climb. It must be rolled about its longitudinal axis to the target azimuth and pitched over toward the target. The missile must be accelerated and given any necessary corrections along its roll, pitch, and yaw axes, while various engines must be ignited and terminated at precise times. In addition, the reentry vehicle must be armed and separated from the missile. These operations are performed by the flight control system through two basic subsystems: (1) the autopilot subsystem (or attitude control) and (2) the inertial guidance subsystem or radio.

An inertial guidance system is completely independent of ground control. It is capable of measuring its position in space and computing a trajectory that takes the payload to the target. It also generates steering signals to properly orient the missile, signals the engines to cut off at the proper time, and signals the warhead to prearm.

When a ballistic missile is launched, it will pass through several phases of flight, beginning with the powered (boost) phase, proceeding through the mid-course (coasting) phase, and ending with the terminal (reentry) phase. A typical flight profile is shown in figure 18-1.

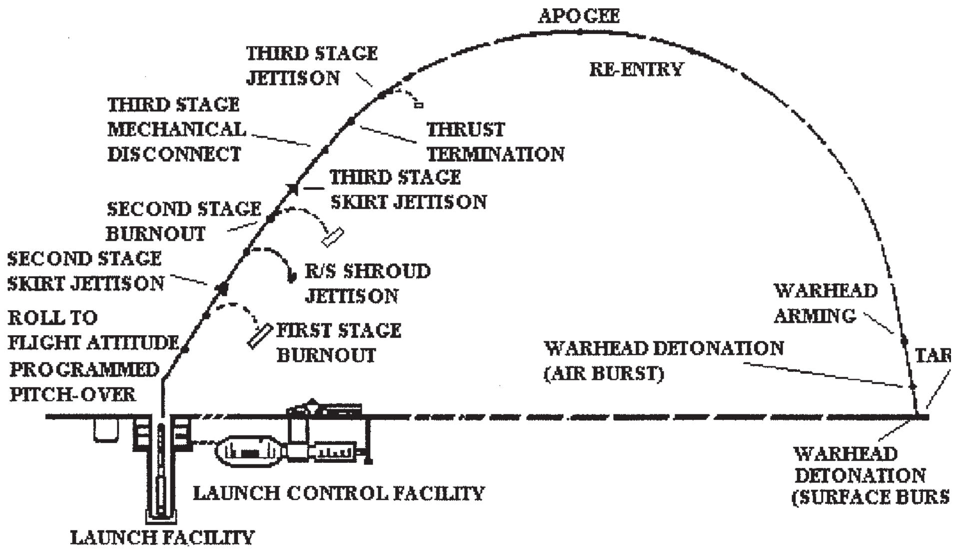

Figure 18-1. Typical ICBM flight profile. (*Reprinted from* Air University, *Space Primer*, unpublished book, 2003, 17-3.)

Reentry Vehicles

A ballistic missile is only powered for a short time during flight. The total flight time for an ICBM is about 30 minutes, but powered flight lasts only five to 10 minutes. The remainder of the time is spent “coasting” to the target. The velocity of powered flight may reach 15,000 mph, or Mach 20, but it really is gravity that does the work of getting the payload to the target. Once an ICBM-borne vehicle begins to encounter atmospheric drag during reentry, aerodynamic heating and braking begins. Induced drag and lift affect the reentry vehicle’s trajectory. There are no control surfaces on a true ballistic reentry vehicle. It acts more like a bullet as it falls to the target.

Reentry vehicles have two means of dealing with the heat developed during reentry into the atmosphere: heat sink and ablative. Heat-sink vehicles disperse heat through a large volume of metal, while ablative surfaces are coverings that absorb heat and slough off of the reentry vehicle, carrying away the heat. Continued use of heat-sink vehicles became impractical because of the tradeoff between RV weight, booster size, and range of the payload. The use of ablative materials helped reduce these problems.

Reentry is incredibly severe, with a necessary tradeoff between survivability and accuracy. In general, steeper reentry angles yield more accurate ballistic vehicles. However, the steeper the angle, the greater the temperature encountered and G-loading (stress caused by maneuvering during reentry) induced on the RV. The challenge is to design a reentry vehicle that will not vaporize from the heat or break up from the G-loading when reentering the earth's atmosphere and yet will maintain the needed accuracy. During development of reentry vehicles, an intense program, including shock tests, materials research, hypersonic wind-tunnel tests, ballistic research, nose-cone drop tests, and hypersonic flight, was used to optimize design of the reentry vehicles.

There are several design requirements for an RV. Foremost is the ability to survive the heat encountered during reentry; the internal temperature must be kept low enough to allow the warhead to survive reentry. A body reentering the atmosphere at speeds approaching Mach 20 experiences temperatures in excess of 15,000 degrees Fahrenheit (F). In practice, the RV never reaches this temperature because of a strong shock wave ahead of the blunt body that dissipates more than 90 percent of this energy to the atmosphere. As the RV reenters the atmosphere, it encounters tremendous deceleration forces—as high as 50 Gs, or 50 times the normal force of gravity. All internal operational components must function under these extreme conditions and additionally must withstand the high lateral loads and intense vibrations encountered.

An RV may be deflected from its calculated trajectory by aerodynamic lift forces. Stability, assisted by a form of attitude control and further augmented by some means of averaging deflection, must be designed into the RV. An arming and fusing mechanism must also be incorporated into the RV to prevent nonprogrammed weapon detonation. From a defensive standpoint, the higher the terminal velocity, the less likely an RV will be intercepted. Higher velocity also decreases the probability of missing the target due to atmospheric deflection. Further, an RV must have a sensing mechanism to indicate the proximity of the target and to arm the warhead. What must also be considered is that the weight of the vehicle must be kept to a minimum in order to maximize the range of the weapon.

Nuclear Weapons Effects

Nuclear weapons effects are normally divided into three types: residual, long-lived, and initial. Residual effects are those which begin about one minute after a nuclear detonation, and they continue for about two weeks. These effects include fallout and its associated radiation, discussed below. Long-lived effects include the subsequent damage to the environment and some radiation concerns, also discussed below. The initial effects are generally the most germane to military matters. There are six primary nuclear weapons effects:

1. Electromagnetic pulse (EMP)
2. Nuclear radiation
3. Air blast
4. Ground shock
5. Thermal radiation
6. Dust and debris

Each of these initial effects can be compared to naturally occurring phenomena. An electromagnetic pulse is similar to lightning bolts, which produce a tremendous surge of electrical current and generate huge magnetic fields—both of which affect electrical equipment. Depending on the altitude of the explosion, EMP effects can occur for thousands of miles around a nuclear detonation.

Nuclear radiation is similar to a powerful x-ray and varies depending on the weapon-burst option used (fig. 18-2). Radiation resulting from a nuclear detonation includes x-rays, gamma rays, neutrons, and ionizing radiation. These forms of radiation are emitted not only at the time of detonation (initial radiation) but also for long periods of time afterward (residual radiation).[2]

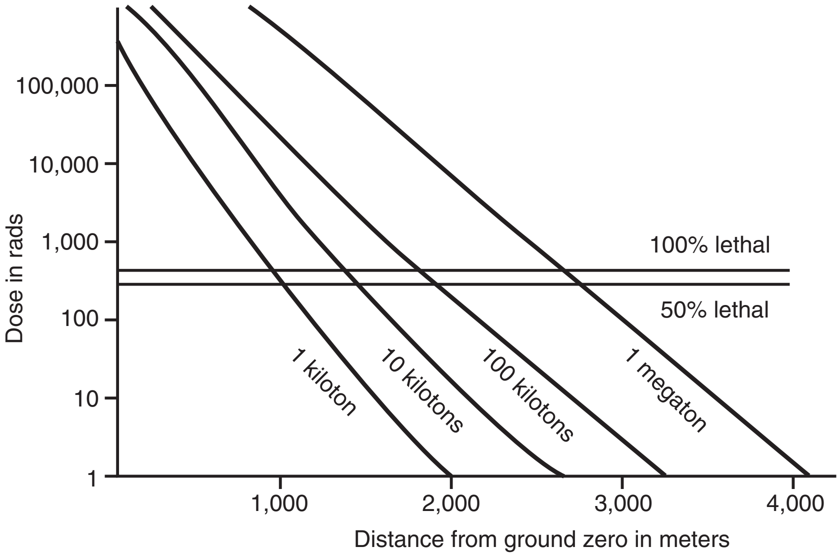

Figure 18-2. Nuclear weapons effects versus distance. (*Reprinted from* Air University, *Space Primer***,** unpublished book, 17-6.)

An air blast is the wind generated by the detonation. These winds can be 10 times stronger than those found in the most powerful hurricane. They actually "slap" the earth hard enough to contribute to the ground shock at the detonation site. The ground shock is nearly 250 times worse than the greatest earthquake. The lateral accelerations are transmitted over large distances at very high speeds.

Heat is another product, with the sun's thermal radiation a useful comparison. The temperatures in the fireball reach upwards of 14,000° F. As a comparison, the sun's surface temperature is approximately 11,000°.

Finally, a ground burst will generate large amounts of dust and debris. The debris can bury undamaged structures while the dust clouds can act as sandblasting equipment on aircraft and missiles flying through them.

The most familiar phenomenon relating to both blast effects and target hardness is overpressure. This is measured in pounds per square inch (psi). A one-cubic-foot block of concrete exerts one psi on the ground beneath. Stacking a second block on the first will increase the pressure to two psi and so forth. Five Washington Monuments placed atop of each other equate to 500 psi; a sonic boom registers a mere 0.3 psi.

Blast overpressure is heightened by the interaction of the primary shock wave and a reflected shock wave. The primary wave is radiated outward from ground zero and compresses the air in front of it. This wave will strike the earth and reflect upward and outward, creating the reflected wave. This reflected wave moves faster than the primary wave because the air resistance has been decreased by the passage of the first wave. The primary wave will be reinforced by the reflected wave, forming a Mach front. A drawing of this phenomenon would resemble the letter Y, with the intersection of the Y termed the *triple point*. Below the triple point, the two blast waves will strike like a single powerful blow. Anything above the triple point is the overpressure. Table 18-1 shows the effects of overpressures on building materials.

Table 18-1. Overpressure sensitivities

Structural element	*Failure*	*Approximate side-on peak overpressure in PSIs*
Glass windows, large and small	Shattering, occasional frame failure	0.5–1.0
Corrugated asbestos siding	Shattering	1.0–2.0
Corrugated steel paneling	Connection failure followed by buckling	1.0–2.0
Wood-frame construction	Failure occurs at main connections, allowing a whole panel to be blown in	1.0–2.0
Concrete or cinder block wall panels, 8–12 inches thick (unreinforced)	Shattering	1.5–5.5
Brick wall panel, 8–12 inches thick (unreinforced)	Shearing and flexure	3.0–10.0

The power of a nuclear explosion is almost incomprehensible, but the following example may help to put it into perspective. Five million one-ton pickup trucks loaded with TNT would have the same explosive yield as a single five-megaton nuclear weapon. A surface burst of this weapon would yield the following results at a distance of 3,200 feet (0.6 miles) from ground zero:

- Fireball diameter: 2.8 miles
- 5.5 billion kW hours of x-rays
- 14,000 degrees
- 250 G lateral acceleration
- 500 psi
- 3,500 mph winds
- 20 inches of debris
- Debris weighing as much as 2,000 lb. impacting at 250 mph

The effects on people are shown in table 18-2. Doses of radiation are described in units of roentgen equivalent mammal (REM). REM is a standard measurement of radiation effects on humans. One REM is the equivalent of one roentgen of high-penetration x-rays.

Table 18-2. Nuclear radiation effects on people

Dose in REMs	*Radius in feet from 20 kiloton air burst*		*Probable effects*
	Unprotected persons	*Troops in covered foxholes*	
0–80	5,550	4,200	No obvious effects. Minor blood changes possible.
80–120	5,250	3,900	Vomiting and nausea for about one day in 5–10 percent of exposed persons. Fatigue, but no serious disability.
130–170	4,800	3,750	Vomiting and nausea for about one day followed by some symptoms of radiation sickness in about 25 percent of exposed persons. No deaths anticipated.
180–260	4,500	3,600	Vomiting and nausea for about one day followed by some symptoms of radiation sickness in about 50 percent of exposed persons. No deaths anticipated.
270–390	4,200	3,300	Vomiting and nausea in nearly all persons on first day, followed by other symptoms of radiation sickness. About 20 percent deaths within two to six weeks after exposure. Survivors convalescent for up to three months.
400–550	3,900	3,000	The midlethal dose. Vomiting, nausea, and radiation sickness symptoms. About 50 percent deaths within one month. Survivors convalescent for up to eight months.
550–750	3,750	2,850	Vomiting and nausea in all persons within a few hours, followed by other symptoms of radiation sickness. 90 to 100 percent deaths. The few survivors convalescent for six months.
1,000	3,600	2,550	Vomiting and nausea in all persons exposed. Probably no survivors.
5,000	3,000	2,250	Incapacitation almost immediately. All persons will die within one week.

ICBM Development in the United States

At the end of World War II, the United States and the Soviet Union recruited as many German scientists as possible to aid in the development of their respective missile programs. Each began their own research programs into the use of missiles as weapons. Funding and weight limitations prevented these programs from quickly advancing. It wasn't until 1954 that Air Force Secretary Talbott directed all necessary steps be taken to advance the Atlas ICBM project.

On 27 October 1955, a contract was awarded to produce another ICBM, the Titan I. The Thor and Jupiter intermediate-range ballistic missile (IRBM) programs also began in December of 1955, with the highest possible priority. The Army had responsibility for all short-range (under 200 miles) surface-to-surface missiles. The Navy had control of all ship-based missiles, and the Air Force got all other surface-to-surface missiles.

The first US IRBM was the Thor (fig. 18-3). It was deployed in the United Kingdom between 1959 and 1963. The Thor was housed horizontally in an above-ground shelter. It had to be raised to the vertical position and fueled before launch. Its propellants were RP-1 (a high-grade kerosene) and liquid oxygen. The Thor had a range of 1,500 nautical miles (nm) and could place a one-megaton warhead within 4,600 feet of the target. The Thor design would later be used as a satellite launch booster.

Figure 18-3. A test Thor takes flight at Cape Canaveral, FL, on 5 December 1959. The small particles falling away from the rocket are ice formed from frozen condensation on the outside of the chilled liquid oxygen tank. (USAF photo)

Figure 18-4. Atlas, the Air Force's first ICBM, was a national priority and one of Gen Bernard Schriever's major achievements. (USAF photo)

First-Generation ICBMs

The first Atlas D ICBM was launched 9 September 1959 at Vandenberg AFB, California. Gen Thomas D. Power, commander-in-chief of Strategic Air Command, then declared the Atlas operational. Only six days later, a Minuteman research and development tethered launch occurred at Edwards AFB, California. This was a model with inert second and third stages and a partially charged first stage. It had a 2,000-foot nylon tether to keep the missile from traveling too far. On 31 October 1959, the first nuclear-tipped Atlas was placed on alert at Vandenberg AFB. Deployment of the Atlas continued in three versions, the D, E, and F models. The D model was housed horizontally in an above-ground, nonhardened (or soft) building and erected for launch (also, three D models were in soft, vertical gantries at Vandenberg AFB). For in-flight guidance, the Atlas used a combination of both radio and inertial systems (fig. 18-4).

The E model incorporated many improvements over the D model. Perhaps the most significant was the replacement of radio guidance with an all-inertial system, making the E model invulnerable to jamming. The E model was also housed horizontally, but it was in a semihard "coffin" launcher that was buried to reduce its vulnerability to blast and overpressure. The F model was kept in an underground, hardened silo and raised to the surface by an elevator for launch; this was called "hard silo-lift." The silo was nearly 180 feet deep.

The Titan I was also being developed and deployed in a configuration similar to the Atlas F. Both used the same propellants and the same silo lift technique. One primary difference was in the command and control. The Atlas F system had one launch control center connected with, and in command of, one silo and missile. The Titan I system had three silos connected to the underground launch control center. Another difference was that the Titan I used a radio-inertial guidance system similar to the Atlas D. The sixth and last Titan I squadron became operational at Mountain Home AFB, Idaho, on 16 August 1962. Only four months later, on 20 December, the last Atlas F squadron at Plattsburgh AFB, New York, achieved operational status.

Even as these milestones were reached, the days of the first-generation ICBMs were numbered. The newer Titan II and Minuteman ICBMs were more survivable, quicker reacting, and more economical to operate and more reliable. On 24 May 1963, Gen Curtis E. LeMay, Air Force chief of staff, announced the phaseout of the Atlas D and E and the Titan I. By its completion, that phaseout also encompassed the Atlas F, with the last Atlas F being removed from alert at Lincoln AFB, Nebraska, on 12 April 1965 and subsequently shipped to Norton AFB, California, for storage.[3]

Second-Generation ICBMs

The second generation of ICBMs, the Titan II and the Minuteman, shared only one characteristic—they were housed and launched from hardened underground silos. The Titan II was a large, two-stage, liquid-fueled missile that carried a single warhead. Its range was about 5,500 nm. The missiles were deployed at three wings. Davis-Monthan AFB, Arizona, was the home of the first operational wing. McConnell AFB, Kansas, and Little Rock AFB, Arkansas, were the homes of the other two.[4]

The Titan II offered five distinct advantages over the Titan I. First, the Titan II's reaction time was reduced from 15 minutes to less than one minute because it used storable hypergolic propellants (fuel that, upon being mixed, ignites without external aid, i.e., a spark). Second, it used an all-inertial guidance system, a major improvement over its radio-controlled predecessor. Third, the missile carried the largest and most powerful warhead ever placed on a US missile. Fourth, each launch complex contained only one missile, instead of the cluster of three used in Titan I; this separation enhanced survivability. And last, the Titan II was designed to be launched from inside its silo, that is, without being elevated to an above-ground position. This limited the missile's vulnerability to damage except during the earliest stages of flight.

The Minuteman is a three-stage, solid-fueled missile housed in a remote launch facility. Its range is in excess of 5,500 nm. From the beginning, it was intended to be a simple, efficient, and survivable weapon system. Its main features are reliability and quick reaction.

The first Minuteman, the Minuteman IA, went on strategic alert during the Cuban missile crisis of October 1962. President Kennedy later referred to this missile as his "ace in the hole" during negotiations with the Soviets.

The Minuteman II became operational in 1964 and replaced many of the Minuteman I missiles. This system, known as the LGM30F or more simply the F model, was more than 57 feet long, weighed over 73,000 pounds, and, like the Minuteman I, carried a single warhead.

Whereas Titan crews consisted of two officers and two enlisted technicians, the Minuteman crews are composed of only two officers. A single Titan missile was controlled from its launch control center (LCC). The Minuteman is operated by a similar procedure, but the crew controls 10 to 50 missiles.

Because the Titan was increasingly expensive to operate and was hampered by a series of accidents, the Reagan administration announced its deactivation in October 1982. The system deactivation began in 1984, and the last Titan II wing was deactivated in August 1987. The Bush administration began deactivation of the Minuteman II to comply with Strategic Arms Reduction Treaty (START) requirements. The last Minuteman II was removed in 1994.[5]

Third-Generation ICBMs

While Titan II missiles were deployed in only one model, the Minuteman series spanned several models. The latest, and only operational version, is the Minuteman IIIG. The last Minuteman III was deployed in July 1975. It is almost 60 feet tall and weighs approximately 79,000 pounds.[6] The Minuteman III originally carried three reentry vehicles, each capable of striking a different target. The Minuteman force was downloaded to single reentry vehicles after 2002 based on the Moscow Treaty (or Strategic Offensive Reductions Treaty [SORT]).[7]

The Minuteman is hot-launched (ignition occurs in the silo), and the missile flies out through its own flame and exhaust. An Avcoat material protects the first stage from the extreme heat generated during this process.

The most recently deployed US ICBM was the Peacekeeper. However, the Peacekeeper was retired from duty in 2005, again following the Moscow Treaty.[8] The Peacekeeper was a four-stage, solid-fuel missile which originally replaced 50 Minuteman III missiles at F. E. Warren AFB, Wyoming. These missiles were deployed in converted Minuteman silos. The first 10 Peacekeeper missiles achieved operational alert status in December 1986 as part of the 400th Strategic Missile Squadron.

The Peacekeeper was 71 feet long and weighed 195,000 pounds—nearly three times the weight of a Minuteman III. This allowed it to carry up to 12 reentry vehicles, although 10 was the operational configuration. The missile was about 7.5 feet in diameter through all four of its stages.

Peacekeeper missiles were housed inside a reinforced steel canister within a silo. They were cold-launched using a technique similar to the system used by the SLBM submarines. At the bottom of the canister was a launch ejection gas generator (LEGG). A small rocket motor in the LEGG was fired into 130 gallons of water contained in a reservoir; this created steam pressure that pushed the Peacekeeper up and out of the canister prior to ignition of the first stage.

The Peacekeeper was protected during launch and in the missile's flight environment by an ethylene-acrylic rubber coating. No ablative material was needed because of the cold-launch. The Peacekeeper was further protected inside its canister by Teflon-coated urethane pads. Nine rows of pads were used to protect and guide the missile smoothly up and out of the canister during launch. The pads fell away when the missile cleared the canister.

In compliance with the Moscow Treaty, Peacekeeper deactivation began in 2002, and the final Peacekeeper was removed in September 2005.[9] The silos have been kept intact, a change from past deactivations. Adam Hebert reports that then–Maj Gen (sel) Mark D. Shackelford, director of requirements for Space Command, said that "the Air Force has decided that launch control centers and silos are 'not to be destroyed.' Instead, this infrastructure will go into indefinite 'mothball status' to ensure that the facilities will be available in case the need for them arises."[10] Also many parts of the Peacekeeper missiles will be reutilized. The reentry vehicles will be "transferred to the Minuteman III program to replace the aging warheads and the booster components will be recycled for space launches."[11]

Current ICBMs

The presently deployed ICBM force consists only of Minuteman IIIG missiles deployed as follows:

- 150 at Malmstrom AFB, Montana
- 150 at Minot AFB, North Dakota
- 150 at F. E. Warren AFB, Wyoming

The Minuteman III (LGM-30G) "G" model is a three-stage, solid-propellant, inertially guided ICBM with a range of more than 6,300 miles. It employs a multiple independently targetable reentry vehicle (MIRV) system with a maximum of three reentry vehicles. The post-boost control system (PBCS) provides maneuvering capability for deployment of the reentry vehicles and penetration aids. It is comprised of a missile guidance set (MGS) and a propulsion-system rocket engine (PSRE). The G model is maintained on alert in a hardened, underground, unmanned launch facility (LF) (fig. 18-5), just as the F model was. The LFs are situated at least three miles apart and are also at least three miles removed from the LCC. Each LF in the squadron is connected to other squadron resources by a buried cable system. When necessary, this allows one LCC to monitor, command, and launch its own 10 missiles (called a flight) and all 50 missiles in the squadron.

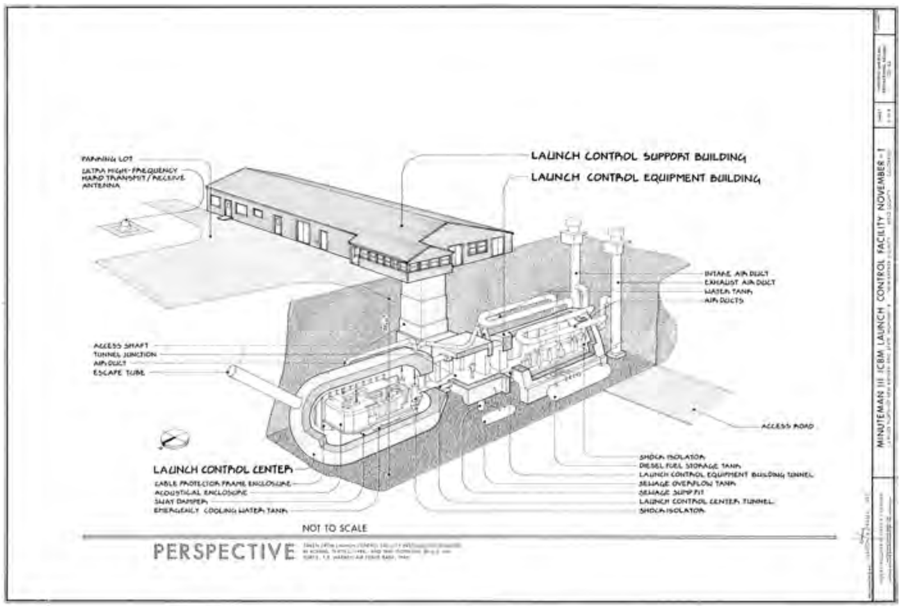

Figure 18-5. Minuteman launch facility. **(***Reprinted from* Air University, *Space Primer*, unpublished book, 2003, 17-8.)

The Minuteman II missiles are currently being enhanced and modified to maintain the viability of the force until at least the year 2020. On the missile itself, the solid propellant of the first- and second-stage motors is being washed out and repoured while the third-stage motors are being remanufactured. Part of this endeavor is to find an environmentally acceptable propellant replacement. The rapid execution and combat targeting (REACT) service life extension program (SLEP) is designed to provide long-term supportability of the system's aging electronics components. It also modifies the LCC, allowing real-time status information on the weapons and communications nets to correct operability problems, improve responsiveness to launch directives, and provide a rapid retargeting capability. Peacekeeper ICBM reentry vehicles have been modified under the safety-enhanced reentry vehicle (SERV) program and are replacing the current Minuteman MK12 reentry vehicles (RV) in phases; this modification is expected to be complete in 2012.

Figure 18-6. Minuteman III. A maintainer looks over a Minuteman III in a silo about 60 miles from Grand Forks AFB, North Dakota, in 1989. (USAF photo)

Three solid-propellant rocket motors make up the propulsion system of the Minuteman G model (fig. 18-6). The first stage uses a Thiokol M-55 solid-propellant motor that generates 200,400 pounds of thrust. The second-stage motor is built by Aerojet (SR19-AJ-1), and it develops 60,700 pounds of thrust. These stages are identical to those of the Minuteman F model. The third stage uses a single fixed exhaust nozzle with the liquid injection thrust vector control (LITVC) system and roll control ports for attitude control. The third stage is a Thiokol SR73-AJ-1 motor that delivers 34,500 pounds of thrust. For thrust termination, there are six thrust termination ports mounted at the forward end of the third stage. These “blow out” when the missile reaches the desired point in its trajectory, from which it will deploy the weapons payload. A shroud protects the payload during the early phases of the missile’s flight. Deployment of the reentry vehicles and penetration aids (designed to confound enemy defenses) is accomplished by the PBCS, a “mini fourth stage.” The PBCS fires periodically to provide maneuvering vectors during deployment of the payload and penetration aids. This process allows the G model to hit up to three separate targets at different ranges with great accuracy.

US Submarine-Launched Ballistic Missiles

In 1955, the National Security Council requested an intermediate-range ballistic missile for the defense of the United States. They further decided that part of the IRBM force should be sea-based. As a result, the Navy was directed to design a sea-based support system for the existing liquid-fueled Jupiter IRBM. This led to the development of the Special Projects Office (SPO) by the secretary of the Navy. The SPO was tasked with adapting the Jupiter IRBM for shipboard launch. Originally, the Jupiter was an Army missile designed for land-based launches. Because of the unique handling and storage requirements, there were numerous issues with the storage and safety of liquid propellants aboard submarines. As a result, the Navy began an effort parallel to the Air Force in the development of solid-fueled rocket motors.

Breakthroughs in solid fuels, which resulted in smaller and more powerful motors, occurred in 1956. Reductions in the size of missile guidance, reentry vehicles, and warheads further aided in smaller missile technology. The first solid-fueled missile incorporating this new technology was named Polaris. The first submarine launch of a Polaris occurred in July 1960 from the USS *George Washington*. Three hours later a second missile was successfully launched. These two shots marked the beginning of sea-based nuclear deterrence for the United States.

Since then, the Fleet Ballistic Missile (FBM) has progressed through Polaris and Poseidon to the Trident I and the only remaining SLBM in service, the Trident II. The Poseidon included MIRV capability, while both generations of Trident provided increases in range and accuracy. There have been other changes as well. The launcher system evolved from compressed air units to steam-gas generators, while the missile fire control system has developed through semiconductor and solid-state electronics to the present microchip technology. Missile guidance systems now use in-flight stellar updates, and navigation has matured from external fixes to onboard computers.

The first nuclear ballistic missile submarine was constructed by cutting a fast-attack submarine (USS *Scorpion*) into two pieces and inserting a 16-tube missile compartment section. Since then, several classes of submarines have been designed and built specifically for the FBM mission. The Ohio-class (726-class) submarine is the newest generation of fleet ballistic missile submarine (SSBN). The first submarine of this class was deployed in 1981. This is the same class of submarines that carry the Trident II strategic weapon system (SWS) and missile.

Polaris

The Polaris (A-1) program began in 1957; later versions were called A-2 and A-3. Its innovations included a two-stage solid propulsion system, an inertial navigation guidance system, and a miniaturized nuclear warhead. Production ended in 1968 after more than 1,400 missiles had been built. The last version, the A-3, had an increased range (2,900 miles compared with 1,700 miles for the A-2 model) and multiple warhead capability. The missile was replaced by the Poseidon SLBM and later by the Trident.

Poseidon

The Poseidon (C-3) weapon system was deployed on Poseidon (Lafayette- and Benjamin Franklin-class) submarines, carrying 16 missiles each. The Poseidon submarine was similar to the one that carried the Polaris. Now out of service, they were deployed from Charleston, South Carolina, and Holy Loch, Scotland.

Trident I

The Trident I (C-4) backfit weapon system was initially deployed on Poseidon submarines starting in 1979. The Trident I system consisted of the Trident I missile and updated launch and preparation equipment. The Trident I missile had increased range and accuracy over the Poseidon (C-3) and was deployed on early Ohio-class submarines in 1981. The updated weapon system included many improvements resulting from new technology. The Trident I missile was phased out of service following the Nuclear Posture Review.

Trident II

The Trident II (D-5) was deployed on the later Trident (Ohio-class) submarines, starting in March 1990. This weapon system consists of Trident II missiles and a combination of new and modified preparation and launch equipment. The Trident II missile is significantly larger than the Trident I because of the increased size of the first stage motor, giving it a greater payload capacity. The latest electronics give it improved reliability and maintainability. The launch platform is basically the same submarine that carries the Trident I, deployed from naval submarine bases at Bangor, Washington, and Kings Bay, Georgia. Trident II missiles are also provided to the United Kingdom, which operationalizes them with its own warheads on the missiles and deploys them on Vanguard-class submarines.

Current SLBM—Trident II D-5

The Trident II D-5 is a three-stage, solid-propellant, inertial- and stellar-guided SLBM. It has a range of over 4,000 nm (over 4,600 statute miles). It carries a MIRV reentry system and is deployed on Ohio-class submarines.

Figure 18-7. Trident II. First launch of a Trident missile on 18 January 1977 at Cape Canaveral, Florida. (USAF photo)

Three solid-propellant rocket motors make up the propulsion subsystem of the Trident II D-5 missile (fig. 18-7). Each stage of the D-5, like the C-4, contains nitroglycerin and nitrocellulose-based propellants in the motor casing. The motor casing for the first and second stages is constructed of graphite and epoxy, while the third stage of the D-5 consists of Kevlar/epoxy materials. These materials are lighter than those used in the Trident I. The first stage is approximately 26 feet long, almost seven feet wide, and weighs 65,000 pounds. Stage two is eight feet long, seven feet wide, and weighs approximately 19,000 pounds. The third stage is 10 feet tall, 2.5 feet in diameter, and weighs 4,200 pounds. A single movable nozzle, actuated by a gas generator, steers each stage. Like the C-4, the third stage of the D-5 is surrounded by the PBCS and the RV mounting platform, which operate much like those for ICBMs.

The Trident II D-5 is 44 feet in length, approximately seven feet in diameter, and weighs 130,000 pounds. Like the Trident I C-4, the D-5 employs an aerospike during first-stage burn. The nose fairing is constructed of Sitka spruce and jettisons during second-stage burn. All other airframe characteristics of the D-5 are the same as the Poseidon C-3 and the Trident I C-4.

Ohio-Class Submarine

Only 14 of the original 18 Ohio-class submarines remain in service. In the early 2000s, the first four ships were retired along with the missile they were designed to carry, the Trident C-4. Each is 560 feet long, 42 feet in beam, and has a submerged displacement of 18,750 tons (fig. 18-8). Although over two times larger than the

Figure 18-8. Ohio-class ballistic missile submarine. US Navy's Trident nuclear-powered submarine USS *Alaska* (SSBN 732) is guided into an explosives handling wharf at the Naval Station. (US Navy photo by Gene Royer)

Franklin-class in volume displacement, the Ohio-class requires only 16 officers and 148 enlisted crew members. The Ohio-class submarine carries up to 24 Trident II missiles.

Notes

1. V2ROCKET.COM, "A-4/V-2 Makeup—Tech Data & Markings," http://www.v2rocket.com/start/makeup/design.html (accessed 8 May 2009).
2. AtomicArchive.com, "Nuclear Radiation," http://www.atomicarchive.com/Effects/effects14.shtml (accessed 18 May 2009).
3. "SM-65 Atlas," Federation of American Scientists Web site, http://www.fas.org/nuke/guide/usa/icbm/sm-65.htm (accessed 8 May 2009).
4. "SM-68B Titan II," Federation of American Scientists Web site, http://www.fas.org/nuke/guide/usa/icbm/sm-68b.htm (accessed 8 May 2009).
5. National Park Service, "Strategic Arms Reduction Treaty and Disarmament of Minuteman II (1990s)," in *Minuteman Missile Historical Resource Study*, http://www.nps.gov/archive/mimi/history/srs/hrs3-2a.htm (accessed 8 May 2009).
6. Air Force, "LGM-30 Minuteman III," Fact Sheet, http://www.af.mil/factsheets/factsheet.asp?id=113 (accessed 8 May 2009).
7. DOD, Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, "Moscow Treaty: Article-by-Article Analysis," http://www.dod.mil/acq/acic/treaties/sort/sort_axa.htm (accessed 18 May 2009).
8. Ibid.
9. Ibid.
10. Adam J. Hebert, "The ICBM Makeover," *Air Force Magazine* 88, no. 10 (October 2005): 35.
11. Ibid.