S E C T I O N II

CONSTRUCTION

PART I -- INTRODUCTION

The Construction Branch had the responsibility in the field for the supervision and inspection of the actual construction phases of the contract.

The Construction Branch operated one Resident Engineer Office located at each complex. Each Resident Office was staffed with a Resident Engineer, one military Project Officer, six to eight inspectors, and was supplemented by Engineer Student Trainees and Junior Engineer Trainees.

The Construction Branch maintained a staff in the Area Office which handled the distribution of mail to the Resident Offices, correspondence, progress reporting and coordination of construction and technical assistance to the field personnel. During the final inspection period, the Area Office staff was increased for the preparation of deficiency lists, final inspection reports and tabulation of deficiencies.

PART II -- SCOPE OF WORK

The design Architect Engineer was Daniel, Mann, Johnson and Mendenhall and Associates, 2706 Wilshire Boulevard, Los Angeles 57, California.

The original contract consisted of three (3) identical missile complexes in the vicinity of Ellsworth Air Force Base, South Dakota. Each complex consists of three (3) Missile Silos, three (3) Propellant Terminals, three (3) Equipment Terminals, one (1) Control Center, one (1) Powerhouse, one (1) Portal Silo, one (1) Air Intake Structure, one

(1) Air Exhaust structure, two (2) Antenna Silos with connecting Antenna Terminal, two (2) Blast Locks, Launcher Area Filtration Structures, twelve (12) Tunnel Junctions and the necessary Type A, B, C, D and E Tunnels to interconnect the entire facility. All of the above structures are constructed underground.

The underground structures were divided into three shock zones. The shock zones designations were Zone "A" - 50G, Zone "B" - 19G and Zone "C" - 3G. All piping and mechanical equipment (air conditioning units, diesel engines, pumps, etc) and conduit light fixtures and electrical equipment (transformers, panels and motor control centers) were either shock mounted (rubber or spring) or built to withstand the shock requirement for the zone in which it was installed. Any piping or conduit crossing from one structure to another or from one shock zone to another was required to have a flexible connection. The complex configuration is shown on Appendix B, Tab 1, Page 2-56.

The reinforced concrete Missile Silos have a finished diameter of 40' - 0" and the walls are 2' - 0" thick. The foundations are 6' - 0" thick. Each silo is 155' deep and is equipped with hinged double pivot type reinforced concrete doors 3' - 7 3/8" thick. The upper cap of the silo flares outward for additional strength and bearing.

The Propellant Terminals are cylindrically shaped with an inside diameter of 37' - 6" and are of reinforced concrete. The walls are 18" thick, the foundation slab is 6' - 6" thick and the structure is 40' - 11 1/2" from the bottom of the foundation slab to the top of the roof. The roof is 6' - 0" thick with a roof access opening of 10' - 0" I.D.

The Equipment Terminals are cylindrically shaped with a 40' diameter and are of reinforced concrete. The height of the structures from the bottom of the foundation to the top of the roof is 70' - 6". The thickness of the concrete foundation is 7' - 2". There are four (4) levels in the terminals. The roof of each terminal is 6' - 0" thick. The Missile Silo, Propellant Terminal and Equipment Terminal, with adjoining tunnels, comprise a launcher area as are shown in Figure

The Launch Control Centers are dome shaped, 40' - 4" high with a diameter of 100' - 8 1/4" at the base, and are of reinforced concrete with prestressed footing. The domes are 24" thick at the base and 14" thick at the peak. The floors are shock mounted reinforced concrete slabs. The I.D. of the domes at the first floor are 95' - 5" and at the second level are 37' - 11". These structures provide quarters and mess facilities for men as well as the launch control and guidance equipment. The kitchen facilities are shown in Appendix B, Tab 2, Page 2-57.

The Powerhouses are dome shaped, 45' - 8" from main floor to peak, with a 118' - 8" inside diameter of bases and are of reinforced concrete. Footings are 8' - 0" x 4' - 6". Domes are 2' - 6" thick at the base and 1' - 6" at the top quarter. The Powerhouses have two wells each for the permanent water supply. The Powerhouses have acoustical baffles for sound dampening. Baffles are shown in Appendix B, Tab 3, Page 2-58.

The Air Intake Structures are cylindrically shaped, with 62' diameter and a height of 43' - 0" and are of reinforced concrete.

The walls are 18" thick, the base is 5' - 6" thick and the thickness of the roof is 5' - 6". The height of the air intake pipe is 17' - 0" above the top of the concrete roof.

The Air Exhaust Structures are cylindrically shaped, 58' - 6" from the bottom of foundation to the top of the roof; the outside diameter of the structures are 35' - 0" and the structures are of reinforced concrete. The walls are 1' - 6" thick, the foundations are 4' - 6" thick and the thickness of the roof is 5' - 1 1/2". The diameters of the openings in the roofs are 16' - 0".

The Antenna Silos are of reinforced concrete. The structures are cylindrically shaped, with the foundations being 6' - 0" thick and the walls 15" thick. Each Silo is 65' deep and 14' - 9" in diameter, and is equipped with double pivot type doors, 3' - 6" thick. The openings in the roofs are 14' - 9" x 16' - 0".

The Antenna Terminals are "T" shaped to connect and service the Antenna Silos. The outside dimensions are 24' - 0" by 36' - 0" and the inside diameter is 16' - 6".

There are two Orientation Targets at each of the three sites. The base of the substructures are 24" x 7' - 6" x 7' - 6" and walls are 9" thick. The outside diameter of the upright portions from the top of the base slab is 9' - 10". The width of the steel grate platforms is 24". The height of the steel handrail is 3' - 5". The structures are of reinforced concrete. A 6" x 8" pipe runs upward through the centers of the upright portions and the areas around the pipes are filled with Vermiculite.

The Type "B" Tunnels have inside diameters of 8' - 0" and the length of each tunnel is 486'. The floors are 9" thick concrete. Tunnel shells are of multiplate corrugated steel.

The Type "A" Tunnels at each complex have a total length of 611' - 0" with an inside diameter of 9' - 0". The width of the steel floors is 7' - 1 1/2" and are 2' - 9" below the center line of the tunnel. The tunnel shells are of 3 gauge liner plate steel and the bottom of the tunnels has a 4" concrete floor. Appendix B, Tab 4, Page 2-59 shows tunnels and tunnel junctions.

Type "C" Tunnels are cylindrically shaped and have angle points at 9' - 5 3/8" west of Equipment Terminals and at 23' - 6 3/4" northeast of Missile Silos. Their fire walls are 10' - 0" northeast of Missile Silos. Their inside diameters are 9' - 6" and the tunnel shells are of 3 gauge liner plate steel. Their floors are of 6" concrete fill. The angle points are 12 WF 40 steel and the firewalls are of 1/2" steel plate over 9 U 13.4 framing members with a 2" thick asbestos board and concrete filler.

The Type "D" Tunnels are cylindrically shaped. The length of the east and west portions from center of LOX Vent Pipe to the center line of the north and south portions is 36' - 10 1/2" and their inside diameter is 12' - 0".

The height of the LOX Vent pipe from the 2' - 0" concrete base to finish grade is approximately 57' - 8". The tunnel shells are of 3 gauge corrugated liner plate. The bottom of the Type "D" Tunnel has 6" concrete fill.

The length of the east and west portions of the "Dogleg Tunnels" from North and South portion of Type "D" Tunnel is 6' - 0". The lengths of the North and South portion of these tunnels from the centerline of the East and West portion to the Missile Silos are 12' - 0". Their inside diameter is 6' - 6".

The Type "E" Tunnels have a length of 281' (this includes "I" section at Blast Lock No. 1). Their inside diameter is 5' - 0" and the inside diameter of the vent pipes from Type "E" Tunnels to Blast Lock No. 1 is 3' - 10". The inside diameter of the pipe at Blast Lock No. 2 is 24'. The shells are of 10 gauge corrugated multiplate steel.

Drainage for all tunnel sections is to the nearest tunnel junction or blast lock which is equipped with a sump pump for transfer to ground surface. Each tunnel junction and blast lock has at least one (1) sump pump.

The Launcher Area Filtration Facilities have cylindrically shaped pipes 40' long and are of 12" channel beams (20.7 pounds per foot). The vent stacks are 21' - 10" above the top of the Northeast end and have inside diameters of 5' - 0". The base of the structures is 2' - 0" thick. The base of the structures have dimensions of 2' - 0" x 10' - 6" x 52' - 5". The Southwest ends of the structures are 18' - 6" x 2' - 10" x 19' - 0" in diameter. The structures are of reinforced concrete.

Tunnel Junction No. 1, 2, 4, 5, 7 and 9 are of 12" channel (20.7 pounds per foot). The length of the North and South portions is 16' - 0 1/2" and the inside diameters are 15' - 6" tapering to 9' - 0" at the Type "A" Tunnels. The length of the east and west portions is 8' - 2 3/4" and their inside diameters are 15' - 6" tapering to 9' - 0" at the Type "A" Tunnels. They have 1/4" steel plates at the side and 6" channel (10.5 pounds per foot) pound removable central panels for walkways. The Junctions are connected with 16' WF-88 yoke beams with reinforced concrete protecting seals.

Tunnel Junctions No. 8 have shells of 12" channel (20.7 pounds per foot) shells. The length of the north and south portions is 36' - 8 3/4" and have an inside diameter of 15' - 6". The length of the east and west portions is 23' - 9" and the inside diameters are 15' - 6" tapering to 9' - 0" at Type "A" Tunnel. The walkways are of 1/2" plate steel at the sides with WF 6C (10.5 per foot) removable central panels. The junctions are connected with 16 WF 88 yoke beams with reinforced concrete seals. The bottoms of junctions have 3/4" of concrete fill.

Tunnel Junctions No. 10 are of 12" channel 20.7 pound steel. The length of the structures between the Powerhouse and the Control Center is 99'. The diameter of that portion of the junctions that ajoins the Powerhouse and the three portions east of the Type "B" Tunnels is 32' - 0", The diameter of the "B" Tunnel is 8' - 0". The diameter of the Type "A" Tunnel is 9' - 0". The diameter of the "X" portion of Tunnel Junction No. 10 is 16' - 0", and the diameter of the portions that contain tanks is also 16' - 0". Tunnel Junctions No. 10 are connected with 16 WF 88 steel beams and are sealed with reinforced concrete.

Tunnel Junctions No. 11 are of 12" channel iron 20.7 pounds. The structures are "X" shaped 36' - 0" by 32' - 0". The diameter of the pipes are 16' - 0" and the floors are 12' - 5" wide. Tunnel Junctions No. 11 are connected with 16 WF 88 steel beams sealed with reinforced concrete. The S 46 floors are concrete fill. There are also steel working floors with removable central panels.

Tunnel Junctions No. 12 shells are of 12" steel channel beams 20.7 pounds and are "T" shaped. The finished diameter of the north and south portions is 15' - 6" tapering to 9' - 0" at Type "A" Tunnels. The finished diameter of the east and west portions is 16' - 0" and it is 12' - 6" to the tank bulkhead. The length of the north and south portions is 32' - 0 1/2". The width of the steel walkway in the east and west portion is 12' - 4" and is 14' - 2" in the north and south portions. The bottom of the junction is covered with concrete fill and the joints are of 16 WF 88 with concrete seals.

Tunnel Junction No. 13 shells are of 3 gauge corrugated steel plate and are "T" shaped, 36' - 9" x 22' - 0" and the finished diameter of the structures is 12' - 0". The floors are of concrete fill 6' - 8" wide. The joints are of 16" wide flange steel 64 pounds.

Tunnel Junction No. 14 shells are of 3 gauge corrugated plate. The structures are 31' - 3" long with a finished diameter of 12' - 0". The concrete walks are 6' - 8" wide.

Blast Locks No. 1 are constructed of reinforced concrete. The floors are 3' - 0" thick in the east and west sections and 4' - 6" thick in the north and south sections. The walls are 24" thick in the east and west portion and 2' - 6" thick in the north and south portion. The ends are 2' - 0" thick. The inside lengths of the north and south portions are 75' - 8", the widths are 12' - 0" and the heights are 14' - 0". The inside lengths of the east and west portions are 53' - 0", the inside widths are 12' - 0" and the inside heights are 10' - 0".

Blast Locks No. 2 are "T" shaped and constructed of reinforced concrete. The inside lengths of the east and west portions are 44' - 4", the inside widths are 12' - 0" and the inside heights are 8' - 6". The inside heights of the north and south portions are 14' - 0", the inside lengths are 32' - 0", and the inside widths are 21' - 0". The walls in the north and south portions are 2' - 10" thick and the roofs are 4' - 6" thick. The roofs on the east and west portions are 24" thick and the floors are 2' - 10" thick. The floors in the north and south portions are 4' - 6" thick and the roofs have the same thickness.

The Portal Silos are cylindrically shaped. The finished diameters are 29' - 6". The base slabs are 6' - 0" thick. The walls are 1' - 3" thick and the roofs have varying dimensions in thickness from 11' - 0" to 3' - 3 7/8". Each Portal Silo has two doors 10' - 6" long, 10' - 6" wide and 3' - 6" thick. The stairways and walkways are of steel, and the personnel entrance is equipped with a steel revolving door and a 20 ton freight elevator.

The roads to all three complexes are of bituminous surface. Roadbeds were regraded and resurfaced from main highways to each site, and where no roads existed, new roads were built. All sites have bituminous surfaced roads within their areas connecting all structures. Appendix B, Tab 5, Page 2-60.

The Surface Facilities at each complex consist of a sewage stabilization pond, five seal chambers, a waste clarifier, an RP-1 filling station, a 7' - 0" high #9 wire - 2" mesh security fence with three strand barbed wire barriers at the top, curbs, culverts and guideposts, and all sites were seeded and mulched with crested wheat grass, Slender wheat grass and Bluestem (Western) wheat grass with straw and hay for mulching. Also included in the Surface Facilities are an electrical manhole, 6 vent shafts and an access shaft. Appendix B, Tab 6, Page 2-61.

UTILITIES

The utilities during construction (as required by specifications) were supplied by the contractor. All three sites had commercial power. In some instances (such as large concrete pours) emergency power was provided in the form of portable generators.

Water was supplied (as per specifications) from the permanent wells located in the Powerhouse Area, with pumps and piping provided by the contractor.

Communications were provided early in the contract by the use of two-way radios. Later in the contract when the permanent underground telephone lines were installed, telephone service was available to the contractor and Corps of Engineers, as well as SATAF.

Portable air compressors were used for all air tools on the job.

ACCESS TO SITE

Access to Complex 1A was by traveling east on Highway U. S. 14-16 and an all weather county road from the Highway to the complex. The county road was paved (asphalt) approximately midway through the contract under a contract administered through the South Dakota State Highway Department by the U. S. Bureau of Public Roads, using Air Force funds.

Access to Complex 1B was by traveling South on South Dakota Highway 79 and an access road built under Contract No. DA-5850. The access road was provided with a double bituminous surface and paved (asphalt) under Contract No. DA-5919 late in the contract.

Access to Complex 1C was by travel north and west on Highway U. S. 14 - South Dakota 79 and South Dakota 34, and an access road built under a contract administered through the South Dakota Highway Department under the USBPR. The access road was paved (asphalt) under the above contract approximately midway through Contract No. DA-5919. Layout and mileage to each complex is shown on Appendix B, Tab 7, Page 2-62.

Railroad facilities did exist near all sites at an adjacent town.

The Corps of Engineers and SATAF had helicopter service available to all complexes and each complex had a designated landing area for the helicopters.

VICINITY MAP

Appendix B, Tab 8, Page 2-63 is a map showing the location of the three complexes. The average of 68 miles separating the three complexes was a consideration in both time and cost.

TOPOGRAPHY

The topography of the areas in which the missile complexes are located (vicinity of Ellsworth Air Force Base, South Dakota) is on the flat ridges in the slightly erroded Great Plains just east of the Black Hills in western South Dakota. The local economy is primarily of a sparsely populated agricultural-cattle ranch type.

PART III -- GEOLOGY OF THE COMPLEXES

The geological characteristics of the three complexes varied from site to site. The boring logs, which were part of the contract drawings, clearly show the different materials encountered at all three complexes. The following is a summary of the geological characteristics:

COMPLEX 1A

The complex was covered with 3 to 4 feet of topsoil. The surface elevation is 3,075.0 feet. Under the topsoil, the overburden consisted of from 4 to 10 feet of silty sand and from 10 to 30 feet of coarse sandy gravel laying unevenly on the top of the Fox Hills formation. The Fox Hills formation is approximately 75 feet thick in this area and is located 30 to 35 feet below the ground surface. This formation is a silty or clayey fine sand, tannish gray to brown in color with 12 inch to 18 inch concretion layers. Below the Fox Hills formation is the Pierre shale formation which grades gradually from the tannish sand of Fox Hills formation to the gray of the Pierre shale. The shale has numerous bentonites and joints. The shale is over 1,700 feet thick in this area. Boring Logs, Appendix B, Tab 9, 10, 11, Pages 2-64, 2-65, 2-66.

WWW.CHROMEHOOVES.NET

COMPLEX 1B

WWW.CHROMEHOOVES.NET

The complex was covered with approximately 6 inches of topsoil.

The surface elevation was 3,394.0 feet. Under the topsoil the over-burden consisted of from 5 to 14 feet of silty or sandy clay and from 8 to 14 feet of sands and gravels. In some areas, the over-burden lays on the top of the Niobrara chalk, and in other areas the chalk is covered with a thin layer of Pierre shale or silty clay.

The Pierre shale in this area is calcareous. The Niobrara chalk is 220 feet thick and is a calcareous shale at the top. It grades into a firmer chalk with numerous bentonites and shaley seams. There are few joints in the chalk and they follow no set pattern. The Niobrara chalk is of the upper cretaceous in age. Boring Logs; Appendix B, Tabs 12, 13, Page 2-67, 2-68.

<u>Complex 1C</u>

The complex was covered with approximately 12 inches of topsoil. The surface elevation was 2,955.0 feet. Under the topsoil the over-burden consisted of from 4.5 feet to 27 feet of sandy and overlean clay, with gravelly clay and gravelly silty clay present midway through the formation. The over-burden lays on top of the Niobrara chalk formation. The top 8 feet to 12 feet of Niobrara chalk is friable and moist, and is tan or gray and brown in color. The lower half of the chalk formation contains many bentonite seams varying in thickness from .01 to .30 feet. The upper half of the formation is virtually free from any of these bentonite seams. The Niobrara chalk in this area is approximately 150 feet thick as is underlayed by the Curlite shale, which is approximately 500 feet thick in this area. Boring Logs; Appendix B, Tabs 14, 15, page 2-69, 2-70.

Complete geological reports and boring logs of all three complexes are on file in the office of the District Engineer, Engineering Division, Omaha, Nebraska.

PART IV -- EXCAVATION AND BACKFILL

General

The geological description of the materials encountered during the open cut and shaft excavation have previously been outlined.

Underground bench marks were provided at Complex 1A and Complex 1C for checking rebound of the foundation surface of the Powerhouse. No underground bench marks were provided at Complex 1B. These bench marks were provided by the Government and were checked once a week, from the beginning of the open cut excavation, until the Powerhouse floor was placed.

These bench marks were installed by the Government approximately one year prior to the start of Contract No. DA-5919. The bench marks were constructed by inserting a specially built 4" tube with ears on the bottom. When readings were taken, a tape with a hook on the end was dropped into the tube and hooked on the ears of the tube. The tape when then stretched to the proper tension by using a scale, and readings were taken to the near thousandth of a foot. Very little movement was recorded at either complex.

The first physical work on this contract was stripping topsoil. The topsoil was stockpiled to be used later in the contract after the area was backfilled.

Open Cut Excavation

The first phase of excavation was the open cut excavation and was performed on a two 10-hour shift, six day per week schedule. The work was accomplished by DW-20's and DW-21's. Dozers were utilized as pushers and rippers. The open cut was from surface level to an average of 40 feet. The Powerhouse, Control Center and Tunnel foundations were set at the bottom of the open cut excavation. Access to the open cut areas was by means of sloping ramps excavation at the time the open cut was accomplished. This operation required from eight to ten weeks depending on the weather. The nature of the soil was such that it permitted very steep angles in the excavation. This hindered work close to the banks due to falling rocks and gravel. Later a fence 18 inches high was placed around the open cut area at the top of the chalk to keep rocks and gravel from rolling into the excavated area.

Originally Complex 1A was scheduled to be the lead site, but due to delaying factors on DA-5683, the permanent wells were completed at Complex 1B first. Therefore, Complex 1B became the lead site with each succeeding site being approximately one month behind. For this reason all prefabricated items, such as forms, templates, etc., were built and utilized at Complex 1B and then moved to the other two sites.

The normal South Dakota weather for January through April was encountered during the open cut operation.

The open cut excavation started at Complex 1A in the launcher areas. A launcher area is one missile silo, one equipment terminal and one propellant terminal with adjoining tunnels. Open cut excavation could not be accomplished in the Powerhouse and Control Center area due to the well under Contract No. DA-5683 not being completed.

When the open cut excavation was completed in the launcher areas, the open cut excavation subcontractor moved his equipment to Complex 1C and returned approximately six weeks later to continue open cut excavation for the Powerhouse and Control Center, "A" and "B" Tunnels and Antenna area.

Complex 1B open cut excavation started approximately two weeks after the work at Complex 1A. The work started in the launcher areas and progressed through the Powerhouse and Control Center area to the "A" and "B" Tunnels and Antenna area.

Complex 1C open cut excavation started approximately six weeks after the excavation at Complex 1A and proceeded along the same lines at Complex 1B.

Shaft Excavation

The second phase of excavation, shaft excavation, was performed on a two 10-hour shift, 6 days per week basis. The shaft excavation started at approximately 40' below the natural ground surface. This operation was accomplished by using a D-7 frontend loader with rear mounted ripper in the shaft. Appendix B, Tab 16, Page 2-71.
The ripper was used to loosen the material and doze the material into a pile. Jack hammers were used to loosen the material in the area around the walls that was inaccessible for the dozer. Appendix B, Tab 17, page 2-71. A crane with a clam shell bucket was used to hoist the excavated material out of the shaft. The crane dumped the material into a dump truck which hauled the material to the designated stock pile area. Appendix B, Tab 18, Page 2-72. As the shafting

progressed, ring beams were installed at specified distances (distance between ring beams varied from 2 1/2' to 5'). The ring beam spacing was maintained by the use of spacer rods and held in place by hard wood wedges. The area between the ring beams was covered with 2" x 2" wire mesh and sprayed with cement grout to prevent material from falling into the shaft and the weathering of the chalk. Appendix B, Tab 19, page 2-73. Blasting was required in few instances where the chalk was too hard to loosen with the ripper.

Throughout the shafting operation, the crane hoisting the material out of the shaft was directed by telephone, from a man at the bottom of the shaft, to the Crane operator. This was done as a safety measure. Other safety measures employed during the shafting operation was a 4 foot fence around the top silo shaft and a fully cage inclosed ladder for access into the shaft. Only minor accidents occurred during the shafting operation.

The shafting operation started with a ring beam type collar set and anchored in place at the top of the shaft. This collar was set accurately by a survey crew and was used for both vertical and horizontal control for the shaft operations. Appendix B, Tab 20, Page 2-74.

The shafting operation encountered many minor delays due to equipment breakdowns.

Ventilation during the shafting operation was accomplished by inducing fresh air from a large blower on the surface through ducts to the bottom of the shaft, Appendix B, Tab 19, Page 2-73. The fresh air forced the stale air out the top and thus kept fresh air in the working area. The diesel engine exhaust on the dozer used in the operation caused some pollution of the air. As the first shaft approached the midpoint in excavation, this problem was remedied by the use of filters on the exhaust pipes which cleaned the exhaust before admitting it to the air.

The shafting operation was accomplished in the months from January to June; therefore, the weather was a factor. The temperature in the shaft was required to be kept above 35^{o} for protection of the sprayed cement grout. To meet this requirement, the contractor built a shelter over the top of the shaft. Appendix B, Tab 21, Page 2-74. The shelter was a wood frame covered with polyethylene. This shelter, in addition to holding in the heat, protected the excavation from rain and snow. A portion of the shelter had to be removed during the mucking operation. This presented a problem in holding temperature above 35^{o}, due to the loss of heat through the open portion. Quite often when the outside temperature was low, the mucking had to be shut down and the shelter closed to allow the temperature to rise in the shaft. These shut-downs seldom exceeded one hour in length, but over a long period of time amounted to a considerable loss of time. The heat in the shaft was supplied by a fuel oil burning heater with a fan for circulation of the warm air. During the coldest weather, as many as five heaters were required to hold the correct temperature; in milder weather only two were required.

Lighting in the shaft during the excavation was supplied by flood lights mounted on the ring beams around the shaft. The major portion of the lights were moved down as the excavation progressed. Some lights remained to afford light in the upper parts of the excavation. The power for the lights was supplied by commercial power. In most instances, a portable generator was held in stand-by in case of emergency during commercial power failures.

There were no serious delays during the shafting operation attributed to supply of materials.

There were a considerable amount of problems causing delays in spraying the cement grout on the walls of the shaft. The major factors causing delays were the frequent plugging of the spray nozzles caused by wet sand. This problem was improved by drying the sand before mixing. The provision for heat in the shaft during application and curing of the sprayed cement grout, as previously discussed, was a delaying factor. The majority of these delays were of short duration, but as discussed under heating of the shaft, these delays accumulated over a long period of time and amounted to a considerable loss of time.

The most serious problems in the shafting operation was the seepage of water into the excavation. Although water seeps were encountered in several shaft excavations, only in Missile Silo No. 1 and No. 2 at Complex 1C were they of the serious nature. At Complex 1C, the water first appeared in Missile Silo No. 1 at approximately 80 feet below the finished grade of the silo. The water had an inflow of approximately 25 GPM. To eliminate this problem, a sump was dug and a pump inserted to pump the water out of the shaft. This sump and pump arrangement was maintained until the water disappeared. When the shafting operation in Missile Silo No. 2 elevation became lower then Missile Silo No. 1, the water in Missile Silo No. 1 disappeared and appeared at the same rate of flow in Missile Silo No. 2. The pumping operation was to dewater, and was moved from Missile Silo No. 1 to Missile Silo No. 2. The sump and pump arrangement remained the same, but a more exact method for leading the water to the sump was needed. This was accomplished by filling the web of the ring beam with 3/4" to 1 1/2" gravel and covering the beam from flange to flange with burlap or perforated polyeythlene to filter the silt from the water to protect the sump pump.

As the shaft excavation proceeded, drain pipes were installed between the ring beams to allow the water to be led to the sump. Modification No. 67 was issued to pay the contractor for the dewatering of the Missile Silo during shafting, concrete placement and up until the Using Service accepted the structure. The inflow decreased from the original 25 GPM to approximately 8 GPM at the time of final acceptance.

The shafting operation, as described previously, was used for the excavation of the Missile Silos, Equipment Terminals, Propellant Terminals and Antenna Silos, from the bottom of the open cut excavation to the bottom of the foundation of each facility.

Tunnel Excavation

Most of the excavation for the tunnels, blast locks and tunnel junctions was accomplished by open cut excavation using the equipment and methods as previously described. Appendix B, Tab 22, Page 2-75. Some handwork, jack hammer work and blasting was required to get down to the final grade. Appendix B, Tab 23, Page 2-75. The tunnel junctions and tunnel sections were prefabricated in Rapid City and transported by truck to the complex. The width, height and weight of some of the tunnel junctions made it necessary for the contractor to secure special permits from the South Dakota Highway Department. Also, it was required to have a flagman ahead and behind the truck. The tunnel section and tunnel junctions were set in place by one and sometimes two 45 ton cranes. The tunnel sections and tunnel junction were set on a sand fill over undisturbed earth. A survey crew was present as the sections or junctions were set in place to assure that they were set to correct grade and alignment.

The excavation for the blast lock foundation was accomplished by hand after the open cut excavation was completed. The blast locks were constructed in place of heavily reinforced concrete. Appendix B, Tab 24, Page 2-76.

Backfill

The material excavated from the open cut excavation was stockpiled and used as backfill and embankment material. The material was placed in 8" lifts and care was taken not to allow any large rocks against the structure. Compaction was obtained by using sheep foot and pneumatic rollers in the accessible area and hand tampers around the structures. Appendix B, Tabs 25, 26, 27, 28, 29, 30, 31, Page 2-77-83 The material was deposited at optimum moisture and compacted to 90% density except under footings and concrete slabs where 95% density was required. All concrete structures were dampproofed prior to backfill and the tunnel sections and tunnel junctions had a sand layer around them to prevent any rock from coming in contact with the structure.

All three launcher areas and the antenna silo area were backfilled first. The contractor returned at a later date to backfill the power-hours, control center and tunnel areas.

After the area was backfilled, the embankment for the on-site roads was built. When the road embankment, Appendix B, Tab 32, Page 2-84 was completed, the sub-base and base course was laid and compacted. The base course was then primed and after the prime had cured, a 1 1/2" bituminous mat was laid.

The area was then top soiled and a security fence erected. The entire disturbed area was then seeded and mulched.

PART V -- CONCRETE OPERATION

Forms

All prefabricated forms were built at Complex 1B. The forms were used at Complex 1B and then moved to the other complexes for use. These forms were built in panels using 3/4" plywood with 2" x 4" framing. The size and shape of the form panels depended on the specific use, such as dome or wall pour involved. These forms were built for specific purposes, such as Powerhouse and Control Center domes, foundation walls, floor slabs, blast locks, pilasters and columns. The supports for the forms varied from two by fours to large timbers, the size depending on the use intended. Appendix B, Tab 33, Page 2-85. Metal scaffolding was used to support many of the forms. The power-house and control center domes were double formed walls with she-bolts or form ties used to hold the forms in position. Appendix B, Tabs 34, 35, Page 2-86.

The Air Intake structure, Air Exhaust Structure, Portal Silo and the top or cap portions of the Missile and Antenna Silos were double form walls using steel-framed plywood panels, with interlocking or keyed frames.

The Missile Silo and Equipment Terminal walls were poured using slip-forms. The slip-forms were constructed of tongue and grooved lumber, Appendix B, Tab 36, Page 2-86, supported by cables and 1" diameter solid steel bars. A working and finishing platform was incorporated under the slip-forms. Appendix B, Tab 37, Page 2-87. The form was constructed with a runway to allow the concrete to be transported to any point in the slip-form. Turn buckle cables were used to span across the diameter of the slip-form to retain the form in the circular shape. The slip-form was lifted by using manually operated pneumatic jacks which raised approximately 1/8" each time it was moved. The 1" diameter rods were the primary support for the form and were anchored solid and accurately at the top and bottom of the silo. The horizontal control for the slip forms was from a point in the center of the silo. The slip form moved at the rate of approximately 8' per 24 - hour day. The concrete was held from 1 to 2 inches below the top of the slip- form during the placing operation. Due to the length of time involved in the placing operation, the concrete has sufficient time to set before the form was moved up. Most embedded items were set flush with the wall face; therefore, the form slip passed over them. A few embedded items were not flush and when the slip form got to them, a section of form had to be removed to allow the form to pass. This slip form method was terminated at the "S" elevation or the bottom of the silo haunch. The forms for the outside face of the haunch were set, the resteel installed and the slip-form operation continued to the "U" line or 16 feet below the top surface of the silo.

Steel Reinforcement

All structures were constructed of reinforced concrete except the tunnels and tunnel junctions, with re-steel sizes varing from No. 4 to No. 18 bars.

The re-steel for the floor slabs, foundations, silo caps and equipment and propellant terminals were placed by normal construction methods. Appendix B, Tabs 38, 39, 40, Page 2-88, 2-89. The re-steel for the Powerhouse and Control Center domes were placed after the inside forms were set. Appendix B, Tab 41, Page 2-89. The outside forms were set after the re-steel was in place.

The re-steel in the Missile Silo walls consisted of two mats of #6 bar placed at 12 inch centers, each way. The re-steel bars were shaped to fit the curvature of the silo and the mats were prefabed in 20' x 20' panels. A re-steel fabrication yard at each complex, Appendix B, Tabs 42, 43, Page 2-90 was used for this purpose.

The re-steel panels were lowered into place by a crane. The mats were held in place by bars welded to the ring beams. Iron workers connected the rebar panels.

The embedded items were installed immediately prior to the placing of the concrete and were set accurately by a survey crew. Embedded items were unistrut, steel plates, etc., for the anchorage of future installations such as pipe supports and spring mounts. The embedded items were anchored to the re-steel mats or to the ring beams or had special anchorage built. The re-steel was welded in special cases to provide for grounding continuity between the grounding mats in the bottom of the silos and the grounding plates located throughout the silo. Additional re-steel was installed around all embedded items and openings in the walls.

Little difficulty was encountered during the re-steel placement operations.

Concrete Materials

Each of the three sites required approximately 35,000 cubic yards of concrete. Due to the different strength requirements of the structures, several classes of concrete were used. The strength requirements were 5,000 psi, 3750 psi and 2500 psi, and for the most part 1 1/2 inch maximum size aggregate was used. Several areas, such as the LCC roof, powerhouse roof and floor slab, antenna and missile silo caps and blast locks used 3/4 inch aggregate. 5000 psi concrete was used on Missile Silo doors.

All aggregate was generally cubical or spherical shaped and was placed in a free drainage area at least 72 hours immediately preceeding the use in concrete. The 3/4 inch and 1 1/2 inch aggregate and sand were stored in separate bins prior to use.

Prestressed concrete was used in the footings for the Powerhouse.

During concrete pouring operations, no more than four cubic yards was placed in one pile prior to compaction. All concrete was placed within 45 minutes of its mixing, and concrete operations were suspended when temperature was below 35 degrees unless the area in which it was being placed was sufficiently heated. Temporary covers, similar to those used for heating the Missile Silos during shafting were used. Appendix B, Tab 45, Page 2-92. The actual temperature of the concrete was held between 50 degrees and 70 degrees. The heights of the concrete pours had to be controlled, and all concrete required a curing period of 14 days. Polyethylene sheets were used to cover the concrete, Appendix B, Tab 44, Page 2-91 or water curing. A maximum capacity for the placing of concrete was 120 yards per hour.

The sand was furnished by L. G. Everist, Inc. and the C. H. Lien Company. The course aggregate was furnished by Pete Lien and Sons, Hills Materials Company and by L. G. Everist, Inc., all of Rapid City, South Dakota.

The cement was furnished by South Dakota Cement Plant, Rapid City, South Dakota, and was hauled by truck.

The batch plants were located on the sites and concrete was hauled to pour areas by transit mix trucks furnished by Crouse Ready-Mix, Inc., and this same company furnished the batch plants.

Central Mix Concrete of Rapid City was the standby company to be used in the event of a breakdown. Their facilities were used on a few occasions.

At the batch plants on the sites, augers were used to transfer the cement from the storage silos to the plant. Aggregate and sand were dumped from separate bins to batch plant by overhead crane with a clamshell attachment. Appendix B, Tab 46, Page 2-91.

Six-cubic yard transit mix trucks (two to six each) were used during each concrete pouring operation. The trucks received the batch and mixed it during the haul to the site of the current pour. Pours were made with cranes, chutes and buckets.

Concrete Placement

The concrete for the floor slabs, beams, thin walls, foundations, terminal roofs, domes and silo caps were placed using a crane, concrete bucket and tremmies or chutes. Appendix B, Tabs, 47, 48, Page 2-93, 2-94. The vibrators used were air operated.

Where concrete could not be placed direct from a concrete bucket, concrete buggies were used to transport the concrete.

The tremmies or chutes were used to deposit the concrete into its final place and to keep the vertical drop to less than 5 feet. Some problems arose in the vibration of the concrete due to extensive amounts of re-steel in some pours. All exterior concrete surfaces were dampproofed before backfilling. Appendix B, Tab 49, Page 2-95, Tab 50, Page 2-96.

The Missile Silo and Equipment Terminal walls were placed by using slip forms. The thickness of these walls varied from 2 feet to 3 feet, depending on the irregularities of the earth surface behind the wall. The concrete was deposited in a hopper and this hopper was lowered into the silo to the elevation of the slip form by a double cable pulley system. The concrete was then dumped into concrete buggies which transported it to the spot where it was to be placed. After dumping, the buggy continued on around the slip form and back to the hopper to be refilled. The concrete was then vibrated with the air vibrators. The slip form moved up at the rate of approximately 4 inches an hour. This operation was a 24-hour a day, 7-day a week operation until it reached the "S" elevation. After the forms and re-steel had been set up to the "U" elevation, which was 16 feet below the top of the silo, the slip form continued to this point. Due to the thickness of the wall from the "S" line to the "U" line (10 feet 9 inches minimum), this operation was considerably slower than the lower portion of the wall.

The cap (top 16 feet) of the missile silos was placed in two pours, utilizing a construction joint in the center. This pour was accomplished by using a crane and concrete bucket.

In all concrete operations, the concrete was mixed in the batch plant and transported to the pour site by a transit mix truck.

During a pour of any size, which could not be stopped, a local concrete company in Rapid City was contacted and held on a stand-by basis in case of emergency.

PART VI -- MISSILE SILO DOORS

The missile silo doors (2 per missile silo) were poured in place by using a crane and bucket. The concrete for these doors was class AAA or 5,000 psi. The doors were reinforced with 2 mats of number 6 and number 11 bars and 4 stirrups which were 3' 7 3/8" thick. Appendix B, Tag 51, Page 2-97, Tab 52, Page 2-98, Tab 53, Page 2-98.

The doors when completed weighed 110 tons.