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LESSONS LEARNED FROM MINUTEMAN PRODUCTION  
AN EXECUTIVE SUMMARY

DEFENSE SYSTEMS MANAGEMENT SCHOOL

NOVEMBER 1974

# DEFENSE SYSTEMS MANAGEMENT SCHOOL



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## PROGRAM MANAGEMENT COURSE INDIVIDUAL STUDY PROGRAM

LESSONS LEARNED  
FROM  
MINUTEMAN PRODUCTION  
STUDY PROJECT REPORT  
PMC 74-2

Clyde W. McLaughlin  
Major USAF

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STUDY TITLE:

Lessons Learned From Minuteman Production

STUDY GOALS:

To assemble and assess the important lessons learned from producing the Minuteman weapon system.

To translate the lessons learned into general areas of concern and recommend actions so that they can be used by other programs entering the production phase.

STUDY REPORT ABSTRACT

The production phase is a critical part of the systems acquisition process due to the high level of funding required and the fact that the operational effectiveness of forces using the weapon system depend on the quality and reliability of the hardware produced.

The purpose of this study paper is to review the trials and tribulations of the Minuteman weapon system which has been in production for over 12 years. The lessons learned from the Minuteman production program are translated into general terms which can be used by other system acquisition programs entering the production phase.

An important consideration is the importance of day-to-day contact with the contractors. How information flows between the government and the contractor is important as well as early identification of problems. The government must also insist in close control of the subcontractors through the efforts of the prime contractor and joint Program Office/prime contractor vendor visits. Proper planning is required to be prepared for changes in the qualified system components and union strikes.

A no-change policy which prohibits unnecessary changes to the qualified design, processes and procedures is an important part of production management. Steps are included in the paper to help in enforcing the no-change policy, and special emphasis is placed on proprietary designs/processes.

A strong Quality Assurance (QA) program is a must during production. Procedures for establishing a thorough, responsive QA program are included in the study. Emphasis is placed on the steps that can be taken by the contractors. A production sampling program is an important part of any QA program. In addition, the value of conducting an Aging and Surveillance program to predict the useful life of the weapon system is explained.

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**LESSONS LEARNED  
FROM  
MINUTEMAN PRODUCTION**

**An Executive Summary  
of a  
Study Project Report**

by

**Clyde W. McLaughlin  
Major                      USAF**

**November 1974**

**Defense Systems Management School  
Program Management Course  
Class 74-2  
Fort Belvoir, Virginia 22060**

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## EXECUTIVE SUMMARY

The production phase is a critical part of the systems acquisition process due to the high level of funding required and the fact that the operational effectiveness of forces using the weapon system depend on the quality and reliability of the hardware produced. Problems during this phase of the acquisition cycle can be quite expensive and operational deployment can be effected.

The purpose of this study paper is to review the trials and tribulations of the Minuteman weapon system which has been in production for over 12 years. The lessons learned from the Minuteman production program are translated into general areas of concern which should be considered by other system acquisition programs entering the production phase. Other programs, then, can benefit by learning from the problems encountered by the Minuteman program.

An important consideration is the importance of day-to-day contact with the contractors. How information flows between the government and the contractor is important as well as early identification of problems. The government must also insist in close control of the subcontractors through the efforts of the prime contractor and joint Program Office/prime contractor vendor visits. Proper planning is required to be prepared for design and process changes in the qualified system components

and union strikes.

A no-change policy which prohibits unnecessary changes to the qualified design, processes and procedures is an important part of production management. Steps are included in the paper to help in enforcing the no-change policy, and special emphasis is placed on proprietary designs/processes.

A strong Quality Assurance (QA) program is a must during production. Procedures for establishing a thorough, responsive QA program are included in the study. Emphasis is placed on the steps that can be taken by the contractors. A production sampling program is an important part of any QA program. In addition, the value of conducting an Aging and Surveillance program to predict the useful life of the weapon system is explained.

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MINUTEMAN PRODUCTION**

**Study Project Report  
Individual Study Program**

**Defense Systems Management School  
Program Management Course  
Class 74-2**

**by**

**Clyde W. McLaughlin  
Major USAF**

**November 1974**

**Study Project Advisor  
COL D. Garvais, USA**

**This study represents the views, conclusions, and recommendations of the author and does not necessarily reflect the official opinion of the Defense Systems Management School nor the Department of Defense.**

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SECTION I  
INTRODUCTION

Purpose of the Study Project

All system acquisition programs that successfully pass the DSARC III hurdle enter into one of the most important phases of the entire life cycle. In the production phase the actual hardware to be used in the field is produced. If the system requires high reliability then extreme care must be taken during production to avoid errors. There is a strong need to maintain the reliability that was built into the system and demonstrated during qualification and operational testing.

Another important feature of the production phase is the relatively high rate at which funds are expended. In general, there is a large increase in the annual fund requirements for systems entering into production. Since funding during production is at an increased rate, it is all the more important that errors or design/process changes be avoided. Problems at this phase can be extremely expensive to correct, and the potential to impact delivery requirements is always present.

The Air Force Minuteman Intercontinental Ballistic Missile (ICBM) system has been under development/deployment for over 14 years. It represents the mainstay of our country's strategic offensive deterrent capability. The first version of Minuteman, Minuteman I, entered into production in 1961. This

version was followed by Minuteman II and finally Minuteman III which is currently in production. The Minuteman III has the sophisticated Multiple Independently-targeted Reentry Vehicle (MIRV) delivery system. A more detailed description of the Minuteman weapon system can be found in Appendix A.

Since the Minuteman weapon system has been in production for over 12 years, the Minuteman Program Office has experienced many of the trials and tribulations that occur during production. Many of the problems encountered were not anticipated and therefore, through the long production process, several important lessons have been learned. The purpose of this study project then is to assemble and assess the important lessons learned from the Minuteman production phase and translate the lessons into general areas of concern on system production problems. The lessons learned can then be used by other weapon system acquisition programs entering the production phase to improve control of their production process. Future programs can benefit by learning from the problems encountered by the Minuteman program and future Department of Defense funds which are in scarce supply can be saved. A secondary purpose of the study project is to improve the author's understanding of the production process by sorting out the problems encountered into common characteristics so that they can be of use in later stages of my career.

## Limitations

This study paper is primarily limited to an assessment of the engineering and production management of the propulsion stages of the Minuteman Weapon System. Other parts of the system, such as the guidance, warhead, ground systems and site activation/deployment, have no doubt had problems associated with the production phase. However, their problems will not be included in this study paper in an attempt to limit the paper to a manageable size. Problems and lessons learned in the fields of program control, logistics and procurement are also not considered in this study paper.

## Organization of the Report

The following sections will develop the problems and lessons learned in the production phase of the Minuteman program. Section II will address the problems and useful management techniques used in working with both prime and sub-contractors. Section III will discuss the problems with, and develop guidelines for, engineering design and manufacturing process changes. Special consideration is given to working with proprietary designs and processes. Section IV will review Quality Assurance requirements and the associated production sampling procedures. Also, covered in Section IV is the propulsion Aging and Surveillance program. Section V will summarize the conclusions of the paper and identify the specific lessons learned. Section V also contains recommendations for additional research.

## SECTION II

### RELATIONSHIP WITH CONTRACTORS

#### Prime/Associate Contractors

The systems acquisition process is a team effort with two basic components. The first component is the conglomeration of government agencies involved in the acquisition process with the System Program Office (SPO) as the focal point. The other component is the team of contractors hired to perform the detailed tasks of design, development and production. The typical system acquisition program has one prime contractor that deals with the government SPO. In the case of Minuteman there is no prime contractor. Instead, the SPO itself functions as the integrating agency for a number of associate contractors. Such a relationship presents the SPO with the responsibility for managing both financially and technically several contractors instead of one. To accomplish its function the Minuteman SPO consists of a team of both Air Force and TRW Systems Group personnel, with TRW providing the Systems Engineering/Technical Direction (SE/TD) support for the Minuteman program (1:2).<sup>1</sup>

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<sup>1</sup> This notation will be used throughout this Study Report for sources of quotations and major references. The first number is the source listed in the Bibliography. The second number is the page in the reference.

The Minuteman SPO is a monolithic program office containing all the functions necessary for program management. Due to the large management task involved under the SPO-Associate concept of management, a large military and Civil Service management force is required.

A significant difference between the Minuteman and other SPO's is the basic functional responsibility of its engineering personnel. Engineering personnel in the standard SPO tend to confine themselves strictly to engineering, leaving such matters as funds, financial management and procurement planning to the Program Control and Procurement and Production Offices. Instead, Minuteman has implemented an internal SPO management system whereby most SPO Air Force engineers provide technical as well as management expertise. These project officers not only are responsible for managing the contractor with respect to technical performance but also with respect to cost and schedule performance. The Minuteman SPO-Associate concept of internal management results in a functionally decentralized organization whereas the standard SPO is centrally organized about the prime contractor. The functional decentralization of Minuteman contributed to the need for a division of the program into a series of discrete, functional elements with each element managed as an entity, a mini-SPO, having cost, schedule and technical performance parameters. For example, there are separate project element Officers assigned responsibility for each propulsion stage working closely with the

associate contractor producing the hardware.

Under the SPO-Associate management approach it is necessary to maintain a close working relationship between the SPO Project Officer and the contractor Program Manager. It is important to establish the SPO Project Officer as the central point of contact between the government and the contractor. All correspondence and direction must be funneled through the Project Officer so that a unified government position is taken on all important matters. If the Project Officer is not a focal point, then the contractor can find himself being yanked in different directions not knowing who he should ultimately take direction from. Since the Project Officer is also held responsible for the budget on his project, he needs to keep on top of any direction given to the contractor so that the necessary funds control can be maintained. Of course, the Project Officer must work closely with his Procurement Contracting Officer so that all actions taken are consistent with good contracting practice.

It is equally important for the associate contractor's Program Manager to be a central point of contact for the contractor. All information flowing from the contractor should come through the Program Manager. He can then be held totally responsible for the actions of the contractor personnel.

In establishing a proper relationship between the Project Officer and the contractor Program Manager there are several

ground rules that must be set down early in the process.

The ground rules basically consist of establishing effective communication. The Program Manager must keep the SPO Project Officer advised of problem areas early in the process without waiting until they have significant impact on program cost, technical and schedule performance. The Project Officer must insist on no surprises. If informed early, the Project Officer can make the proper judgement on the degree of government involvement and assess the impact on his project element and the SPO in general.

One method used to maintain a close working relationship with the contractor is to establish periodic program reviews. Program progress can be assessed and problem areas discussed in sufficient detail to accommodate both the government and contractor personnel. Early SPO involvement can be beneficial in that the SPO deals with all associate contractors and solutions or approaches used by others can be of benefit to a particular contractor in resolving his problem. A typical agenda for a periodic program review can be found in Appendix B (4:ii).

In addition to periodic program reviews, special government inspection/audits have been found to be beneficial in ensuring effective operation by the associate contractors. Government Quality/Manufacturing audits have the advantage of

remotivating employees to correctly perform all operations and stem any trend toward negligent work habits. Government audits get the attention of the contractor's management and usually an internal house cleaning and employee re-indoctrination program results. The company house cleaning gains added emphasis because the employees realize the government customer is keenly interested in the results.

An important tool used to assist production contract negotiations in Minuteman has been the use of Should-Cost Team visits to the contractor's facility. Unfortunately, an adequate competitive environment does not exist in the production phase to assist in ensuring low, fair and reasonable negotiated costs. Should-Cost is defined as:

A technique of contract pricing that employs an integrated team of government procurement, contract administration, audit and engineering representatives to conduct a coordinated in-depth cost analysis at the contractor's/sub-contractor's plants. The objective is to identify uneconomical or inefficient practices in the contractor's management and operations and to quantify the findings in terms of their impact on costs. The result is the development of a realistic price objective which reflects reasonably achievable economies and efficiencies (2:1-1).

In the case of Minuteman, six Should-Cost visits have been made with an estimated overall savings of \$90 million. The savings attributed to the Should-Cost visits are an estimate of the reduction in the contractor's proposed contract price over an above the reduction that would normally be expected in negotiations (16).

There are several potential improvements in the contractor's operation that can result from Should-Cost team visits. The possible improvements are summarized below (3:22,23):

- (1) Use of approved or established labor standards.
- (2) Improve management systems to measure labor efficiency/productivity.
- (3) Improve labor efficiency.
- (4) Reduce scrap rate.
- (5) Reduce overhead.
- (6) Improve make-or-buy system.
- (7) Improve plant layout.
- (8) Improve production planning/control.
- (9) Improve material procurement through price competition.

### Subcontractors

On the Minuteman program the subcontractors play a key role and are an important part of the team effort. The success of a program can rise or fall on the performance of the subcontractor personnel down to the lowest tier. Since they play such an important role, the subcontractors have received considerable attention from the Minuteman SPO.

Unfortunately, the subcontractors can be a significant source of problems in a production program. The severity and number of problems seems to increase with time. This stems from

many factors. As the production program rolls on, a complacency sets in. The subcontractors lack the motivation of the prime or associate since in many cases the subcontractor works on a variety of programs of varying degrees of importance including commercial business. As time passes, there is a decrease in the subcontractor management control as the subcontractor management shifts their attention to other more pressing problems and new business. With the decline in Aerospace business in recent years, companies have shifted their attention and interest to commercial business. The strict manufacturing and quality control imposed by the government may no longer receive proper attention. Personnel changes may result with the desire to put their best people on commercial or new business and the training of replacements may be inadequate.

The quality control of subcontractor efforts may be the first area to suffer. Quality and processing short-cuts may creep in as the "expert syndrome" sets in. There's increasing desire to authorize "minor" deviations and remove what seems to the subcontractor as unnecessary controls. There's a continuing financial pressure to reduce costs and make more money under the fixed price environment. There is a general decrease in the first tier subcontractor quality control surveillance of sub-tier vendors. Finally, there can be a general downgrading of sub-tier quality control audit discipline as time passes.

In an attempt to control the potential subcontractor

problems outlined above, the Minuteman SPO places strong attention on the subcontractor's role in the program and the SPO continually applies pressure on the associate contractors to maintain a constant vigilance on the subcontractors. The SPO requirements for manufacturing and quality control imposed on the associate contractors must be passed on to the subcontractors and enforced. The associate contractor must continually meet with the subcontractor management to obtain their commitment and total awareness of the critical importance of their product. The associate should conduct periodic audits of the subcontractor manufacturing process. The audit should be conducted when hardware is being processed.

Another method of controlling subcontractor performance which has proven to be quite effective is joint SPO/Associate vendor visits. The vendor visits have the following objectives (5:3).

- (1) Motivate the vendor management and work force by impressing them with the importance of their product in the Minuteman Weapon System and the defense of the United States.
- (2) Impart the Minuteman philosophy of maintaining high quality and prevention of design/process changes.
- (3) Identify potential problem areas.
- (4) Motivate the associate contractor management of vendors.

(5) Meet with the local government representatives and discuss SPO management philosophy.

The vendors are carefully selected for SPO/Associate visits based on their criticality to the system and the vendor's past performance. During the visit the vendor is asked to review his program management, quality control procedures, manufacturing process and controls, engineering efforts and configuration control, and personnel training program. The meeting is followed by a plant tour. The SPO team consists of representatives of engineering, production, and quality.

Several benefits have resulted from the SPO/Associate vendor visits. Besides the vendor motivational aspect, several problem areas have been identified. Typical problems found are as follows: lack of overall vendor management attention; poor quality procedures; manufacturing procedures not documented; inadequate and in some cases not being followed; no formal personnel training program; quality documentation inadequate; and poor scrap parts control. A serendipitous benefit of the vendor visits has been the effect of the SPO visits on the associate contractor. Frequently the associate will visit the vendor prior to the SPO visit and correct problem areas in advance.

A major problem which is becoming more serious as time passes is the loss of currently qualified subcontractors. A year ago there were approximately 60 vendor changes and as of

July 1974 the list had grown to 130 which represents an alarming increase. The reasons for the loss of qualified vendors are as follows (6):

(1) In some cases the products used by Minuteman are over 10 years old and are no longer used by any program other than Minuteman. Since the products are no longer competitive some vendors are dropping them from their product line.

(2) Companies close plants where Minuteman products are manufactured for various reasons, such as the plant is no longer a profit making location or safety/pollution rules would require uneconomical facility modifications.

(3) The Occupational and Safety Act (OSHA) has placed new restrictions on processing of certain chemicals and materials. To comply with the OSHA regulations vendors must change their manufacturing process to an unqualified process.

A good example of the type of problems one can encounter when qualified products are no longer available concerns the cork insulation used to cover the external surface of the entire Minuteman missile with the exception of stage I which uses an epoxy material. The cork produced by Armstrong Cork Company is no longer used by anyone but Minuteman. Previously the cork was also used in the auto industry as a gasket material, and now the auto industry uses neoprene. The Armstrong Cork

Company elected to drop the product. This has resulted in an extensive requalification program for the Minuteman program since the cork is a critical part of the missile. There are other companies interested in producing cork for Minuteman but it remains to determine if their product will meet the Minuteman requirements.. The details of the requalification program are not firmly established; however, the process may cost over \$750 thousand (7).

The loss of currently qualified vendors has had a substantial effect on the Minuteman SPO. The vendor losses represent a significant impact on the financial and manpower resources of the SPO. In each case a careful study must be made to establish the requalification program required to ensure that the reliability of the Minuteman missile is not degraded. There is always the risk that a new qualified source can not be found or that a new source which passed the requalification program may later prove to be unacceptable. A significant impact on the cost/schedule of the Minuteman program would result.

A final problem involving contractors which has had a significant impact on the Minuteman program concerns the shut-down of normal production operations due to labor union strikes. There are several potential problems which can occur. The first and most obvious problem is that the SPO might not be able to meet the system delivery requirements. This has not occurred to date; however, only carefully thought-out contingency planning

has prevented a major impact. One learns to appreciate any built-in pads or banks in the manufacturing and assembly process to ride out the downtime due to the strike. It has been found to be advantageous in some instances to allow the company management to build ahead in anticipation of an impending union strike. Another work-around which has been successfully employed is to allow the company management personnel to continue the production process. This approach, however, is fraught with peril, and quality control procedures must be stepped up to ensure that defective hardware is not produced. Even when the strike is over and the workers return to work extra care must be taken to ensure a high quality product. This is especially true if the strike settlement may not be entirely acceptable to the union members. Whether or not there is an adverse financial impact from strikes is debatable; however, one still must plan for the possibility of a strike to be able to absorb the impact on the schedule.

## SECTION III

### SYSTEM DEVELOPMENT AND PRODUCTION

#### Guidelines for Initial Design and Development

The Minuteman experiences in production and deployment have led to several guidelines to be followed during the development phase. They can be summed up by calling for a total attention to detail during design. The designs must be assessed from a producibility standpoint. Further, the equipment designs should lend themselves to evaluation testing and be fully inspectable during production. There are several joining techniques which can lead to problems later and they include spot welds, brazed joints and uninspectable welds. There is no substitute in equipment design for experienced people. The people that have been through the design and development process before and have graduated from the school of hard knocks should get involved early in the design process. Many potential pitfalls can thereby be avoided (6).

The design engineer can not operate in a vacuum. He must also be concerned about how the hardware will be fabricated. A recent problem with the Minuteman III Post-boost Propulsion System (PBPS) is a good example. A system level ground test failed due to a gas pressure regulator failing in the open position and thereby dumping the pressurant. A subsequent failure analysis found that the regulator failed because the

Kynar plastic poppet and seat material had been subjected to methyl ethyl ketone (MEK) and acetone during the system assembly process. The assembly paperwork called for cleaning the pressure tube fittings during assembly but did not specify the type of solvent to be used. Standard industry practice calls for the use of MEK or acetone. Unfortunately, these two chemicals if used in sufficient quantity have an adverse reaction on the plastic material used in the regulator. Freon is now specified for cleaning during the assembly process. The moral of the story is that the design and assembly procedures must be married to ensure that nothing is done during manufacturing assembly that will harm the equipment design (9).

In general, the equipment designer must have a means of transmitting important aspects of the design to the other members of the design/manufacturing/inspection team. One means which was effectively used during the Minuteman propulsion development program was called Classification of Characteristics (C of C). Under this system the designer was able to identify the important characteristics of his design such as materials, and critical dimensions. At each Critical Design Review, the contractor engineering group would review the C of C for each component. C of C information would be useful in other stages of the development process such as when the quality assurance engineers identify the key manufacturing inspection points. The C of C data could also be used later in

the manufacturing process during non-conforming Material Review Board actions.

As an overall comment on the design/development process, the approach of doing the job right the first time can have large returns later on in the system life cycle. While a comprehensive development program can be quite expensive, the costs should be assessed in light of the overall life cycle costs. The development of the Minuteman III Post-boost Propulsion System (PBPS) is a good example of a well organized, thorough development effort. The PBPS system has been exceptionally reliable to date which the following statistics show:

- (1) Propellant leak free storage - 1, 125 years  
(cumulative)
- (2) Strategic alert reliability - 7,158,280 hours  
(MTBF)
- (3) Reliability of 0.99762 with no failures in  
over 75 flights
- (4) PBPS successfully fired after 5 years of  
storage
- (5) Field Maintenance Emergency Response Team  
has never been called on
- (6) No incidents of unsafe conditions.

The conclusion of the above is that the economies of one-time development costs are only apparent long after the investment is made. Other factors must be considered which cannot be

readily assessed in terms of dollars. Removal from strategic alert, retrofit, recycle, and periodic maintenance may cost more than dollars in the overall concept of the defense system (10:4).

#### Guidelines for Design/Process Changes

An activity that occurs during production that can have significant impact on system performance is engineering design and manufacturing process changes. Design and processes never seem to stand still. There is always a stream of changes being processed and all for seemingly worthwhile reasons. Included in the above are class I and class II changes that must be approved by the government and so-called class III changes that the contractor can make without government approval since they deal with internal paperwork not under formal government control. Of concern here is not only changes that may have been authorized but also changes that are made by contractors without formal authorization.

Unfortunately, changes do not always result in a better product or process. The Minuteman program has had several examples where seemingly innocuous changes have had disastrous effects. It is worthwhile to review the details of a few of the examples to show what can happen.

The first example concerns an approved class II change which involved changing the atmosphere used during heat treatment of a seamless steel tube from helium to nitrogen. The

change was made by the subcontractor in an attempt to reduce production costs by bringing the heat treatment operation in-house as opposed to using a vendor. The in-house heat treatment furnace could only use nitrogen. The unfortunate result of the change was that the strength of the material went up when the heat treatment was conducted in the nitrogen atmosphere. All available literature said this would not happen. The increased material strength adversely affected a subsequent processing step involving convoluting the steel tube. The net result was that 80 tubes in various stages of processing were scrapped at a cost of approximately \$400,000 (11).

A second example concerns a failure to follow approved procedures in the processing of a solid propellant motor. After the solid propellant has been cast and cured into the motor case, the procedures call for using a specially designed cable and load cell to pull a central core mandrel out of the cured propellant. In this particular incident, the manufacturing workers were in a hurry and used a substitute cable which was laying nearby. During the core removal process, the unauthorized cable broke and the mandrel snapped back into the propellant which ignited the propellant and blew the steel core mandrel out of the building and started a fire. Two people were killed in addition to the loss of the facility and hardware (12).

The third example concerns a difference between how the hardware was actually being fabricated versus the process called

for in the paperwork. The process in this example involved the gluing of ablative materials into a solid propellant rocket motor nozzle. The drawing called for using the glue only in a finite area; however, the workers that had been making the part from the beginning had been applying the glue over a larger area. During a Quality Control inspection, an inspector caught the discrepancy and insisted that the workers follow the drawing. This change in the manufacturing process resulted in both flight and static critical failures and eventually held up the production line during the failure investigation (6).

A fourth example involves a subcontractor change of a manufacturing process without the associate contractor's knowledge. The subcontractor directed a change to a Stage I steel nozzle housing salt bath heat treatment process without first checking out the process change to see if there would be any deleterious effects. The subcontractor made the change (which was permitted within the existing documentation) because he had occasionally experienced trouble with a nickel plating operation which follows the heat treatment. However, the change was probably not required in the first place since the nozzle housing had been manufactured according to the old procedures for over ten years. The heat treatment process change resulted in small cracks in the housing. Out of 160 housings processed with the new heat treatment procedure, only 40 were considered acceptable. The subcontractor was subsequently

directed to return to the original heat treatment process and an investigation is currently underway to determine if any of the 120 defective housings can be salvaged. The cost impact of this unauthorized process change is not clear at this time but could range from 750 thousand to over a million dollars. Delivery of complete Stage I motors has also fallen behind schedule as a result of this problem (7).

In an attempt to combat the examples of ostensibly minor changes outlined above which have backfired, the Minuteman program has tried to enforce a no-change policy. Simply put, if it's not absolutely necessary to change, it's necessary not to change. If the qualified design/process works - leave it alone. The hardware qualification program actually qualifies everything including the design, paperwork, process and people. No one is smart enough to write a sufficiently detailed specification to include every detail that could be important. Therefore, any change or addition, however minor, may have an adverse effect on the hardware operation. The no-change policy referred to here not only applies to authorized changes, but it also applies to the elimination of unauthorized changes made by contractors.

There are several steps that can be taken to minimize or eliminate changes. The steps are as follows:

- (1) Vigorously publicize the no-change policy to all tiers in the contractor chain. Special emphasis

should be put on "class III" changes where the contractor can make changes without prior approval of the government.

(2) Insist that change control procedures are passed down to the lowest contractor tier and then subsequently enforced.

(3) Ensure that the manufacturing process is accurately documented especially after the hardware has been qualified. If a discrepancy is later found between the paperwork and the process, it is better to change the paperwork to agree with how the hardware is actually being fabricated.

(4) Insist on strict adherence to approved procedures in the manufacturing process. Shortcuts can have disastrous results. This should be reviewed with the manufacturing personnel on a recurring basis.

(5) Call for the hardware design and manufacturing process to be checked together for consistency to preclude the use of any materials during the manufacturing process which may have a harmful affect on the design.

(6) Insist that any necessary change be demonstrated first before committing any substantial amounts of hardware. There is always the possibility that an unexpected reaction may occur which would preclude the incorporation of the change.

(7) Approved changes should be compared with any other changes involving the same hardware since there may be a synergetic effect which would only become apparent when the changes come together. Separately the changes are acceptable but together they may result in unacceptable performance.

(8) Work closely with the government plant representative office personnel to enlist their aid in controlling or eliminating changes. They should be thoroughly indoctrinated in the no-change policy. This should include plant representatives at sub-contractor plants.

(9) All proposed class I and II changes should be closely scrutinized from every angle before acceptance. If not absolutely necessary they should be disapproved. If approval authority for class II changes has been delegated to the local government plant representative's office they should be advised to consult the SPO if there is any question about the acceptability of any class II change. In fact, it may be desirable to cycle all class II changes through the SPO for review prior to acceptance. As a minimum, info copies of class II changes should be sent to the SPO. It has also been found to be advantageous to review class II changes during periodic program management reviews.

## Guidelines for Working with Proprietary Data

The Minuteman program has continually had problems associated with the use of proprietary designs and processes. It is recognized that proprietary data is an inherent part of private industry; however, it has nonetheless been a source of difficulty at various phases of the development and production process. This is especially a problem with subcontractors. It is difficult for the government or the prime contractor to write an end item specification in sufficient detail to thoroughly describe the item. Since a complete design disclosure is not made, it is difficult to be sure that the design/process is locked-up once the hardware is qualified. This is especially true in the case of subcontractors withholding design details from the prime contractor. The government can usually get access to any proprietary data but this doesn't help the prime contractor since the government is required to strictly limit access to the data to government officials. It is possible then for the subcontractor with a proprietary design or process to make changes without anyone's knowledge or approval. Pressure later in the production phase to reduce costs and increase profits can lead to unacceptable changes.

An example will help to show the type of problem one can run into when proprietary designs/processes are involved. The example concerns a proprietary solid propellant gas

generator used on the Minuteman III stage III for roll control. The subcontractor made a change to the propellant without anyone's knowledge. While the gas generator functioned properly, this change resulted in the roll control system not performing properly during a test of a stage III motor. The gas generator subcontractor did not realize the change to his product would affect the complete roll control system. When this problem was surfaced, it was difficult to work because the associate contractor who is ultimately responsible for the successful operation of his stage could not gain access to the subcontractor's plant or the detailed design and manufacturing process data. The associate contractor was in a frustrating position of not being able to work the problem. The associate was forced to turn to the SPO to solve the problem. During a failure investigation at the subcontractor's plant the relatively minor change to the propellant ingredients came to light. The investigation revealed that it was not necessary to change the ingredients in the first place. The problem was in a propellant test technique used during the manufacturing process of the gas generators. The test technique was corrected and the ingredients were returned to the original composition. The net result of this problem was a significant increase in the change control procedures imposed on the gas generator subcontractor.

The preceding example illustrates the problems associated with proprietary designs/processes and suggests steps that can

be taken to minimize the effect of the problem. In this case it was necessary for the government to get involved in the solution of the problem which is a less than desirable position of getting caught between the associate and the subcontractor. This can tend to eliminate the government's ability to hold the associate or prime contractor responsible for his product. The associate can sit back and if things go wrong he is in a position to hold up his hands and say it is the government's fault. If it becomes necessary to use proprietary designs/processes then extra effort should be made to work closely with the subcontractor involved to ensure that he is aware of and supports the no-change policy. He should be made aware of the important part his hardware plays in the success of the system so he can appreciate the fact that any change he may make can have a significant impact on the total operation. If the subcontractor is not aware of how his product fits into the total picture, then he can not appreciate how a minor (and even acceptable) change in his design/process can have an adverse impact on other parts of the system.

It is necessary to ensure that configuration control procedures are passed down to the lowest subcontractor tier. This is especially true when proprietary data are involved. It may be necessary for the associate contractor to identify certain important characteristics of lower tier vendor products so that any proposed changes to these key characteristics

must be brought to the attention of the associate contractor prior to approval. It has also been found to be advantageous to impose increased acceptance test procedures for use in production. This is done in an attempt to identify any changes that may otherwise go unnoticed. Hopefully, the increased 100% acceptance testing will catch any changes before they can result in costly program impacts.

As a final note, consideration should be given to using the absence of proprietary designs/processes as a proposal evaluation criteria in selecting the contractor to develop the system. The lack of proprietary data can be used as an evaluation criteria if this fact is clearly included in the Request For Proposal. One runs the risk, however, of eliminating from consideration a design/process which is clearly superior and desirable for incorporation into the system. As a minimum, the bidders should be asked to identify any proprietary data included in his proposal, and perhaps propose an alternate approach which does not involve proprietary information (13). If the proprietary approach is selected, then the data rights should be resolved and clearly understood by all parties at the very beginning of the development program.

## SECTION IV

### QUALITY ASSURANCE AND SURVEILLANCE

#### Quality Assurance Requirements

Quality assurance (QA) has always been a very important part of the Minuteman program. The QA process has evolved over the years to include a series of controls over contractor operations which clearly contribute to the high reliability of the weapon system. The controls found to be useful to the Minuteman program, which go beyond the requirements of MIL O 9858A, are outlined below. Additional details can be found in Space and Missile System Organization (SAMSO) Exhibit 73-5A (14:1-8).

(1) The contractors are required to establish an internal Quality Audit Group to perform periodic, impartial evaluations of the Quality Assurance Program and the product. The audit group is independent of the activities audited. Product audits will include partial nondestructive disassembly inspection of accepted items on a sample basis.

(2) The contractor's QA organization operating at field sites will have its responsibility and authority clearly defined by company documented policies and procedures with management concurrence at the policy making level. Technical supervision is provided on a directline from the parent con-

tractor QA organization.

(3) The contractors are required to ensure that QA engineers participate in the design process. This includes inputs to all design reviews/audits. Participation is continuous through the design/development cycle. QA approval of the final design and all subsequent changes is denoted by signature. The objective is to ensure the ability to control, measure, test and manufacture; and ensure adequacy, completeness and clarity of QA requirements and criteria for producibility, contamination control and corrosion control.

(4) The contractor's QA program must assure that technical and engineering data required by contract are prepared in accordance with contractual requirements.

(5) The contractor must ensure that the supplier QA program requirements are in accordance with MIL-STD 1535 and the SAMSO Exhibit 73-5A.

(6) The QA program must provide for the review and approval of manufacturing process and test specifications to assure that they are accurate and complete and contain acceptable QA provisions.

(7) The contractor must have a manufacturing inspection and test planning program for all segments of the manufacturing and assembly cycle, which will include flow charts reflecting all inspection and test

points. The program is based on a comprehensive study of the product and engineering requirements; such as drawings, material specifications, process specifications, workmanship standards, design review records, and failure mode analyses, to assure that necessary tests and inspections are performed to verify that the product meets program requirements.

(8) Contractor personnel responsible for manufacture, inspection and control of special processes and operations which require skills and could have an effect upon the quality of critical items and processes must be certified. Certification of personnel for processes or operations such as welding, soldering, radiography, dye penetrant, bonding, etc., must include a formal training program followed by a formal testing procedure to assure the proficiency of each individual. Certification only lasts for a specified period and recertification is then required. A training program is required for all personnel regardless of the criticality of the job to assure adequate skill levels relative to contract requirements.

(9) The contractor must have a workmanship standard for all processes and for fabrication and

assembly operations where workmanship requirements are not covered adequately by design specifications, drawings, work instructions or other readily available control documentation.

The Minuteman program has always made maximum use of the local plant representative offices in pushing the QA program. Critical quality control inspection points are delegated to the plant representatives quality personnel to perform on a 100% basis. This operation has continued throughout the life of the Minuteman program and has been quite successful. The continued government surveillance has kept the contractors sufficiently concerned and contributed to the delivery of a quality product (15).

#### Production Sampling Procedures

Concern for maintaining high quality production led the Minuteman Propulsion Division to establish a QA test program wherein systems and subsystems are randomly pulled off the assembly line and subjected to a static test. The rate of sampling varies with the component. For example, complete propulsion stages are sampled at a frequency of one in twenty. The stage selected for test is subjected to a complete mission duty cycle at simulated altitude conditions. The primary purpose of the testing is to identify any adverse design/process changes that may have crept into the hardware. Quick identification of problem areas helps to minimize the potential

cost/schedule impacts which can occur while the problem is being corrected. Sampling is also done at the component level to further speed up the identification of design/process changes.

A good example of the type of problem that can be found through production sampling was covered in Section III of this study. The Minuteman III PBPS regulator problem was found during a system level production QA test being conducted at Arnold Engineering and Development Center. If production sampling was not being conducted then this problem would have gone unnoticed with a resulting degradation in system reliability. The cause of the problem was quickly identified and corrective steps were taken to preclude any further occurrence.

#### Aging and Surveillance Program

A unique feature of the Minuteman propulsion program is the Aging and Surveillance (A&S) Program. This effort was instigated to assist in identifying the useful life of the propulsion stages. A second objective of the A&S Program is to identify any degradation in weapon system reliability. Since it takes several years to replace an ICBM weapon system, it is extremely critical to look into the future and get as much advance warning on the age limit as possible.

The A&S Program basically consists of getting missile hardware into storage in a controlled environment that simulates the actual environment that the missiles will see in the silos.

The A&S Program consists of two phases with the first phase consisting of hardware from the Full Scale Development (FSD) Program. As soon as the hardware (both components and complete systems) designs become frozen in FSD, hardware was set aside into storage. This was done as soon as possible in FSD to get as much lead time on the production hardware as possible. Later, the hardware was periodically pulled out of storage and tested at different ages to determine if there had been any adverse trends in the performance parameters as a result of age.

The FSD hardware A&S Program is complemented by an Operational Surveillance program which constitutes the second major phase of the program. This A&S program consists of periodically taking the older propulsion systems out of operational use and conducting a static test to identify any adverse performance trends. The data from both the FSD and operational A&S tests are analyzed to predict the useful life of each propulsion stage. Any life-limiting items are identified in the process and carefully tracked.

If there is a weak spot in the A&S program, it would be the extensive storage and test of components in addition to complete propulsion stages. This concern stems from two considerations. The first question is whether the additional component data is really necessary and the second concern is whether component propellant sample tests can be made to

really simulate the real world.

In summary, an A&S program is unquestionably worthwhile. However, the specific details of the program should be carefully assessed to make the program as cost effective as possible.

SECTION V  
CONCLUSIONS

Lessons Learned

Based on the discussion in the preceding sections, the specific lessons learned will be presented in this section. The lessons that follow are provided in general terms so that they can be used by other programs entering the production phase.

Relationship with Contractors:

1) If subsystem project element managers (having responsibility for cost/schedule/technical performance) are used in a program office, then the flow of all information between the government and the contractor should be between the subsystem manager and the contractor program manager.

2) Insist on early and accurate notification of problems from the contractor. No surprises.

3) Establish periodic Program Management Reviews and occasional government audits.

4) Consider the use of Should Cost Team visits to achieve substantial reductions in sole source production contract negotiations.

5) Maintain close control of subcontractors through the following means:

a) Keep pressure on the prime contractor to

maintain a constant vigilance over subcontractors through frequent management meetings and production/quality audits.

b) Conduct joint Program Office/prime contractor vendor visits to review production/quality management.

6) Be prepared for changes in the qualified system components due to vendors dropping product lines, changing facilities and/or processes. Requalification programs are generally required with associated cost and schedule impacts.

7) Be prepared for impacts on production as a result of union strikes. Advanced planning is desirable as well as special quality procedures during and after the strike.

System Development and Production:

1) Institute a no-change policy which prohibits changes in the qualified design, processes and procedures unless they are absolutely necessary. Enforce the no-change policy (especially unauthorized changes) through the following steps:

a) Vigorously publicize the no-change policy to everyone.

b) Insist that change control procedures be passed down to all subcontractor tiers and strictly enforced.

c) Accurately document the manufacturing process.

d) Insist on strict adherence to approved procedures.

e) Demonstrate any approved changes to identify any potentially adverse effects.

f) Enlist the aid of government plant representative offices to enforce the no-change policy.

g) Maintain positive System Program Office control over class II changes.

2) Consider all approaches to eliminating proprietary design/processes. If proprietary design/processes must be used then insist on increasing the following controls:

a) Configuration control procedures

b) Acceptance test procedures.

3) In order to preclude senseless errors, insist on total attention to detail during the development and production phases. Call for inspection of critical operations to make sure errors were not made.

#### Quality Assurance and Surveillance

1) Consider implementing a strong QA program consisting of the following features:

a) Internal contractor Quality Audit Group to perform periodic, impartial evaluation of QA program and the product.

b) Clear deliniation of responsibility and authority of contractor field QA sites.

c) QA engineering participation in design process.

d) Strict compliance with applicable government rules and regulations by all subcontractors.

e) Review and approval by O.A. personnel of all manufacturing process and test specifications.

f) Comprehensive manufacturing inspection and test planning program.

g) Periodic training and certification of personnel responsible for manufacturing, inspection and control of critical processes and operations.

h) Government inspection of critical quality control inspection points.

2) Conduct a QA production sampling test program of system and components to identify any adverse design/process changes.

3) Conduct an Aging and Surveillance program to assist in predicting the useful life of the weapon system.

#### Recommendations for Other Research

In researching this study paper there were several production related topics which could not be pursued due to a lack of time. Additional subjects which show promise for further study include the following:

1) Second source contracting as a means of introducing competition into the production phase.

2) Relations with logistic support to include the steps involved with and timing for transition of

engineering responsibility from the System Program Office to the logistic command.

3) Special procedures for the program control or business management function in the System Program Office.

4) How a Program Management Information System should change when a program transitions into the production phase.

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## APPENDIX A

### MINUTEMAN WEAPON SYSTEM

The Minuteman Weapon System is an intercontinental ballistic missile and represents the nation's predominant strategic deterrence force. The weapon system is now in its third generation and initial development began in 1958. The first successful Minuteman I flight test was conducted at Cape Canaveral in February 1961. The 1000 missile Minuteman force is currently deployed at six Strategic Air Command bases located in North and South Dakota, Montana, Wyoming and Missouri. The latest version, Minuteman III, is currently in production and has the multiple independently targeted warhead capability. The Minuteman III missile is a three-stage solid propellant missile capable of a range of over 5,000 miles and is fired from underground silos by remote control (8:25).

The weapon system was developed under an associate contractor relationship wherein there was no single prime contractor. The associate contractors are under the management of the Minuteman SPO which is assisted by TRW Systems Group which provides Systems Engineering/Technical Direction. The other principal associate contractors are:

The Boeing Company - systems integration,  
installation and checkout.

Autonetics Division of North American Rockwell -  
guidance.

AVCO and General Electric - Reentry vehicle.

Sylvania - ground electronics system.

Bell Aerospace Company - Post-boost propulsion  
system (liquid propellant).

Thiokol Chemical Company - Propulsion stages I and  
III (solid propellant).

Aerojet Solid Propulsion Company - Propulsion  
stage II (solid propellant).

## APPENDIX B

### PERIODIC PROGRAM MANAGEMENT REVIEW AGENDA

- I. Opening Remarks
- II. Review of Action Items
- III. Production Status
  - A. Waterfall or Line-of-balance charts
  - B. Delivery Status
- IV. Significant Accomplishments
- V. System Test Results
- VI. Problem Areas
- VII. Engineering Efforts or Investigations Status
- VIII. Design Changes (Class I and II)
- IX. Vendor and Process Changes
- X. Quality Control
  - A. Material Disposition Review (MDR) Program Status
  - B. MDR Trends
  - C. Acceptance Test Performance Results
- XI. System and Subsystem Reliability
- XII. Aging and Surveillance Program Status
- XIII. Review of Action Items and Agreements