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Contractor Report ARCCD-CR-86008

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ATMOSPHERE ASSISTED MACHINING
OF
DEPLETED URANIUM (DU) PENETRATORS

Charles E. Latham-Brown
Frank Porter
Nuclear Metals, Inc.
2229 Main Street
Concord, Massachusetts 01742

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Doug Vanderkooi
Project Engineer
ARDC

May 1987

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The work described in this report details a method which permits the machining of depleted uranium penetrators under a protective atmosphere. The quality of the DU chips produced under these conditions was such that remelting under specific conditions resulted in high recovery yields of material which is normally considered scrap. The potential for cost reduction is advanced by this approach. <i>Keywords:</i>			

CONTENTS

	Page
INTRODUCTION.....	1
Objective of the Program.....	1
Summary of Project Structure and Project Results.....	1
BACKGROUND.....	2
TECHNICAL DISCUSSION.....	3
Task A Retrofit of Jones & Lamson Lathe.....	4
Task B Chip Handling System.....	5
Task C Premachining Evaluation.....	6
Task C Final Machining Evaluation.....	8
Task D Production Proveout.....	9
Task E Evaluation of Bright Chips.....	11
CONCLUSIONS.....	14
Machining.....	14
Evaluation of Bright Chips.....	15
APPENDIXES	
A - HEALTH AND SAFETY.....	39
B - ECONOMIC ANALYSIS.....	40
DISTRIBUTION LIST.....	42

TABLES

No.		Page
1	SCI atmosphere and NMI production.....16 machining conditions	16
2	Premachining evaluation test data.....17 Task C	17
3	Final machining evaluation test data.....20 Task C	20
4	Rod analysis.....25	25

FIGURES

No.		Page
1	Rubber flap arrangement.....	26
2	Headstock enclosure.....	26
3	Tailstock enclosure.....	27
4	Front enclosure.....	27
5	Console and work area.....	28
6	Conveyor cover.....	28
7	Chip conveyor.....	29
8	Cutaway section of Jones & Lamson lathe.....	30
8a	Drawings delivered to NMI by South Creek Ind. Inc.....	31
9	Chip compactor.....	32
10	Chip compactor assembly.....	33
11	Compactor parts list.....	34
12	Process flow chart for derby manufacture.....	35
13	Fabrication of slugs at NMI.....	36
14	Fabrication of heat treated at NMI.....	37
15	Fabrication of penetrators at NMI.....	38

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INTRODUCTION

OBJECTIVE OF THE PROGRAM

The objective of this effort is to evaluate, under production conditions, atmosphere assisted machining of depleted uranium (DU) penetrators. This study will encompass the comparisons of machining cycle times, tool life, product quality, and in particular, chip quality as generated under these conditions with those of conventional machining using water soluble coolants. The proposed overall goal is to minimize the oxidation of chips both during machining and subsequent handling so that they will become a more suitable material for remelting and so that the very high cost of disposing of chips can be reduced.

SUMMARY OF PROJECT STRUCTURE AND PROJECT RESULTS

When this MM&I project was initiated, some preliminary work, machining the uranium 3/4 Ti alloy used for Kinetic Energy (KE) penetrators under an inert atmosphere of argon had resulted in very promising results. This approach to machining of reactive materials had been actively promoted by South Creek Industries (SCI). Because of the licensing restrictions for handling DU, the experimental machining was carried out at the DoD-AMMRC facility in Watertown, Massachusetts, under the direction of SCI. The preliminary indications resulting from this work were that:

1. Machining of DU at production feeds and speeds is possible and practical, replacing the conventional water soluble coolant by argon and handling the chips generated in an argon atmosphere.
2. The chips produced looked bright and clean and appeared to be suitable for remelting.

It should be noted that this work was carried out by machining cylindrical bars in a single tool, manually controlled lathe. The machining enclosure was a simple rectangular box which also served as the receptacle for the chips generated. The chips were removed from the enclosure manually and compacted in small quantities for the very limited remelting experiments which were carried out.

The principal incentive for the "atmosphere assisted" machining project is cost reduction of the finished (DU) penetrator through better material utilization. At present, for every pound of derby metal introduced into the process at melting, less than half a pound ends up in the shipped penetrator core and about one half pound has to be shipped to and buried at one of the available low level radiation burial grounds. A good fraction of the material which has to be buried consists of chips. Burial costs are high and are becoming higher every year. Therefore, there is a strong incentive to remelt the chips generated in machining. Two approaches are being taken to accomplish this. The first is cleaning, etching, compacting and remelting of chips produced by conventional "wet" machining. The second is that, taken in this project which attempts to produce chips of high quality, free of oxide and uncontaminated by coolant thereby ensuring high yields in the remelting process.

The ambitious task attempted in the present project was to use the very limited data available from the SCI-AMMRC work and to expand this in one step to a full scale production process. This process was to include argon inert gas machining of the preform and of the finished penetrator, handling chips from the lathe to the melting process without exposure to air, and remelting of the chips to a quality billet as well as recirculating the argon. Looking back at the various problems which had to be solved to develop this process to the point where it could be used in large scale production, it is now evident that neither the time, funds nor the engineering capabilities were sufficient to attain our goals. We feel that we have solved the first of the two major goals, namely to demonstrate that machining under argon without water soluble coolants can be done at rates comparable to conventional machining both for premachining and for finish machining. The quality of the chips thus produced is such that they can be remelted with reasonable yields. The second goal, how to handle, compact and melt these chips efficiently and economically, was not achieved and very little if any progress toward this goal can be claimed for the project.

BACKGROUND

Uranium is a very reactive metal. While solid uranium will only oxidize very slowly and form a semi-protective coating in air at room temperature, it will react more rapidly at elevated temperatures or in a finely divided form such as fine chips. Depending on temperature and humidity of the air, uranium will form two principal oxides, UO_2 and U_3O_8 , more complex oxides, hydrides which are extremely unstable, nitrides and complex combinations of the above.

The earliest machining of uranium metal and alloys was done at very slow speeds and with lubricating oils as a coolant. With the large increase in production required by the acceptance of depleted uranium as a superior material for kinetic energy penetrators, machining speeds increased drastically, heat removal became vital and the industry shifted from cutting oils to water soluble cutting fluids.

Uranium will spark (burn) when machined even while flooded under a deluge of water soluble coolant. For the purpose of the proposed work, we can consider that DU chips see temperatures from room temperature to near the melting point at the shear face between the tool and the chip. If oxygen or water are present, some degree of oxidation will take place. The amount of oxidation depends on cutting speeds and feeds, frictional forces, bulk temperature, etc.

In some cases the chip will be entirely consumed and no metallic material will remain. Under present conventional M833 production machining conditions at NMI the oxygen content of chips generated during premachining appears to be approximately 0.1 percent (1000 ppm) while the much finer chips generated at the higher speeds of finish machining contain close to 1.0 percent (10,000 ppm) of oxygen. Extensive flooding of the metal cutting area was adopted to minimize burning and oxidation. The very best material recovery in melting chips produced by conventional machining has been about 70 percent with 30 percent of gross to be buried at approved disposal sites. These melts were composed of approximately 20 percent by weight of compacted briquettes.

The Army has recognized some of the problems inherent in recycling of chips produced by conventional machining techniques used in the production of DU long rod penetrators. The special attention required for cleaning and

processing of conventionally machined chips in a high volume production environment is cumbersome and offers a low percentage of clean quality chips necessary for recycling.

This program was developed to advance the study of chip recycling by eliminating the source of contamination. The machining of DU under an inert atmosphere minimizes metal contamination and yields a much higher percentage of chips for recovery.

The production machining of the M833 penetrator at NMI is carried out in two steps, premachining of the ultrasonic blank (two passes) and the finish machining operation which involves the use of eight different tools. The weight of the starting blank is typically 13.75 pounds. Premachining generates 2.25 pounds of chips; the weight of the blank for finish machining is 11.50 pounds. Finish machining generates 2.9 pounds of chips and a solid nib weighing one half pound. The weight of the finished penetrator is 8.1 pounds. Therefore, 59 percent of the starting blank becomes a finished penetrator while 35 percent is reduced to chips with 6 percent as the remeltable nib.

The use of cold argon and carbon dioxide to cool the cutting area and to prevent burning of chips has been examined for various reactive metals. Under a contract with South Creek Industries (SCI), the Army has shown the applicability of inert gas machining to depleted uranium (MM&T 5824563 Facet 5). This work was carried out on a Pratt & Whitney conventional Model "C" lathe with speeds and feeds similar to those used in finishing penetrators on production equipment. The outstanding finding was that machining carried out in an enclosure filled with argon and with the cutting edge of the tool exposed to a continuous flow of argon, "bright" chips with greatly reduced oxygen and carbon content could be produced. It was also shown that tool temperature could be reduced appreciably and that no obvious excessive tool wear occurred. Therefore to confirm the techniques and findings of the study, this production adaptation is being directed to address the specific points and machining procedures required to produce a finished penetrator.

The work conducted by South Creek Ind. was reported in AMMRC TR83-42 "DU Chip Recovery Program"; Phase I, July 1983. Typical machining conditions for the SCI work taken from the final report of Phase I and NMI's production experience is shown in Table 1.

Some simplifying assumptions were made in generating Table 1; however, the theoretical chip weight per hour gives a comparative measure of the energy expended and the heat generated.

TECHNICAL DISCUSSION

The program of the contract is divided into six specific tasks as follows:

- Task A Retrofit of Jones and Lamson Lathe
- Task B Construction of Chip Handling System
- Task C Machining Evaluation

Task D Production Proveout
Task E Evaluation of Bright Chips
Task F Final Report

TASK A RETROFIT OF JONES AND LAMSON LATHE

In accordance with the contract, South Creek Industries of Scotia, New York, was awarded a subcontract to modify the lathe in such a manner as to permit the machining operation of the DU penetrators to be carried out under a protective atmosphere of inert gas. The Army was instrumental in the selection of South Creek Industries for this assignment by virtue of their previous experience on the program carried out at AMMRC under Contract No. MM&T 5824563, Facet 5.

The lathe assigned to the program was a standard Jones and Lamson, CNC Model TNCA which had been previously used in a conventional machining operation with coolants. It was essential that considerable disassembly be undertaken for cleaning. The lubricating oils and the water soluble cutting fluids as used in normal operations would pose serious contamination problems. This same concern would carry over into the chip handling system that will be addressed under Task B.

In discussions held with NMI, South Creek Inc. first proposed a protective box design similar to that used at AMMRC, which would encapsulate the turning operation. The unit would be modified with a type of rubber flap arrangement which would permit the tool insertion and traversing of the turret head while still maintaining some integrity of the inert gas being introduced into chamber. Figure 1.

However, upon closer examination of the problems of changing work pieces, the physical size of the tool holders and the area of the opening which would permit gas leakage, it was decided that the better solution was to adopt a two chamber system.

The original intent was to have South Creek Industries generate a complete set of engineering drawings from which modifications could be made to the Jones and Lamson lathe. It was determined that this was not practical as the piping of gas lines and the fabrication of the sheet metal covering of the sliding components of the lathe could not entirely be foreseen until the work was actually started. Therefore the required engineering drawings would not be generated until such time as the system was completely operational.

Sheet metal was fabricated that would enclose that portion of the lathe from the head stock to the tailstock including those slide areas by which tool position is regulated. Figures 2 and 3 show the extent to which coverage was necessary.

The front of the lathe was first closed off with a simple plexiglas door. With some trial purging and by the use of MSA oxygen indicators, it was determined that the considerable leakage of the system did not permit maintaining the low oxygen levels that would be required, not only to minimize the oxidation of the chips, but to prevent any possible ignition as well.

The oxygen level required to prevent oxidation of the DU chips was determined by NMI and SCI through SCI's previous experiments to be in the range of 2 to 4 percent. Through the efforts as described in the following text, we were able to achieve levels in the range of 1 and 2 percent.

It was therefore necessary to undertake a much more intensive approach to sealing the outer enclosure. This resulted in more extensive sheet metal changes along with the use of fiberglass and epoxy components and caulking compound to try to seal every possible point of leakage. With the plexiglass door in place, it was first thought that the larger chamber might also be able to be sealed. It was determined that the turret slide area was a significant source of leakage and was difficult to seal because the turret has a two axis movement when in operation. A "window shade" type of arrangement was installed to help seal the openings between the turret and the machine ways as they appeared. This was not sufficient and after some time the cover wrinkled up to the point where it was of no use. As a result, it was necessary to go further back on the machine and extend the enclosure around the whole back, sides and top creating somewhat of a box around the entire unit. The result was a very large chamber which in turn required a large volume of gas to effectively purge the machine as well as being able to maintain the levels required. The design and the physical size of the Jones and Lamson lathe made it quite difficult to seal efficiently and effectively.

Since the machine operator requires frequent access to the chamber for the purpose of loading and unloading of parts, changing tool inserts, clearing chips, etc., the front plexiglass covering was redesigned to permit the use of long rubber gloves, thereby allowing access without having to open the door and release the gas. With this change, it was only necessary to open the door for major servicing. Oxygen monitors were installed to read both the inner and outer chamber atmosphere. When these adjustments were completed, it was possible to achieve oxygen levels of less than two percent within the inner chamber. Figures 4 and 5 illustrate the front enclosure modifications.

TASK B CHIP HANDLING SYSTEM

As was the case under Task A, the design and fabrication of means by which DU turnings would be handled from the inner chamber of the lathe to the point of discharge and collection under protective atmosphere was also under the direction of South Creek Industries as part of the same subcontract.

Upon examination of the conveyor system as used on the standard production machines, South Creek Industries decided to use the same basic mechanism. The modification designed was an enclosure around the conveyor itself. Chutes to the chip discharge part of the inner chamber and the adapters for the storage drum at the point of collection were also included. Access ports at various points of the sheet metal were provided to permit cleaning or the separation of chips should they ball up in transport. An argon gas supply was piped into the base to supplement the argon which would feed down into the conveyor from the inner chamber of the lathe thus insuring complete protection of the chips throughout the transfer. Figure 6 shows the enclosed conveyor with its access door and gas feed.

The task of chip handling was also designed to include the processing of chips to a briquetted form. The process of compacting was to be carried out under a protective atmosphere. During the period of the machining evaluations conducted under Task C, the chips were collected at the end of the conveyor in a protected drum. The briquetting was done manually in air while the compactor was still under construction. This particular point will be covered in more detail under Task E, the evaluation of bright chips. The engineering drawing of Figure 7 illustrates the layout of the conveyor and the adapters to the collection drum.

Figure 8 shows a schematic drawing of the lathe with a cutaway of the inner chamber and the flow path of the chips into the conveyor being carried along to the discharge end and finally into the compactor. In this drawing, the compactor has replaced the simple collection drum used in the early stage of the program.

The actual operation of compacting was to be accomplished by the chips free falling into a chute and then into the sleeve of the packing die. The chute was fitted with a simple push rod to enable the operator to fully charge the die before activating the hydraulic ram. After the compact had been formed, the ram was programmed to retract so as to allow the base plate to be withdrawn to the side to permit the ejection of the briquette. The operation would then be repeated.

Figure 9 is a photograph of the packing die in position under the discharge end of the conveyor with an attached drum into which the briquettes would collect during the machining operation.

Figure 10 is an engineering drawing of the assembly of the chip compactor in its relative position at the end of the conveyor. Figure 11 is the parts list for the assembly with the numbers referenced to the assembly drawing No. NMI-004-000.

A complete set of engineering drawings has been submitted by South Creek Industries upon completion of their area of responsibility. This encompassed the retrofit of the Jones and Lamson lathe, the modification and fabrication of the chip handling system and the design and construction of the chip compactor. The listing is contained in Figure 8a.

At the direction of the ARDC these drawings will not be an integral part of this report. The drawings have been delivered to and will be retained by the ARDC Project engineer.

MACHINING EVALUATION

TASK C PREMACHINING

The objective of this task was to evaluate, under production conditions, atmosphere assisted machining of depleted uranium (DU) penetrators. In performing this evaluation, using as a baseline the current M833 conventional machining method, comparisons were made using a variety of cycle times (speeds and feeds), and associated tool life, as a function of these variations. Particular attention was directed to the quality of the finished product and to quality and configuration of the chips with regard to the recycle

operation. Experiments were conducted with different types of tool inserts for the purpose of getting the chips in a more broken condition thereby allowing a free flow out of the inner chamber. Machining in an inert atmosphere is a totally different situation from operating in the conventional manner with coolant being flooded onto the part and chips in a much more open condition. It was necessary to find inserts which would give the best possible chip configuration. Development of a long stringy chip would be unacceptable because of the tight confines of the inner chamber. Such long chips tend to deflect off the top of the chamber and onto the workpiece and wrap themselves tightly around it thereby interfering with the steadyrests. Because of this situation, it was most important to find those inserts which would produce the best chip for our particular conditions. At the same time, it was necessary to consider the effect on cycle time i.e., feeds, speed, depth of cut. Tool life and surface finish also became major concerns as they impacted on cost and the specifications for the product. In the finish machining operation, experiments were conducted changing the sequence of the steps involved to determine what effect this might have in obtaining the best overall performance. Table 2 is a complete listing of the work conducted in this premachining phase of the program.

It was determined that operating at a slower spindle speed, (1000-1300) revolutions per minute (RPM), tool life increased with less heat being generated, and the chips were physically smaller. However, these benefits were offset by the fact that the radius on the nose of the tool was small and produced a poor surface finish.

Changing to insert R-B Tool Co. No. PD2-8304-P25N with a tool nose radius (TNR) of 0.031 inches, there was an improvement in surface quality with no adverse effect on the chips. Twenty-one bars were machined with this insert at various speeds and feeds. The first fourteen test pieces were done in two passes and the remainder with a single pass. The best results were obtained with a speed of 900 RPM and a feed of 0.009 inch per revolution (IPR). The chips were small and controllable to the point that they did not wrap around the work piece or interfere with the steadyrests.

Seventy bars were machined with a square tool from the Excello Co. which had a 45 degree rake angle (Part No. SN433-4520-E6). The speed for this series was 900 RPM with a feed rate of 0.009 inch IPR. Chatter problems, for the most part were eliminated. With these conditions the chips were at times stringy, although controllable.

The tooling was then changed back to the R-B Tool Co. insert No. PD2-8308 for comparison runs. The remaining bars were processed with the same results as those obtained with the Excello Co. tool. Therefore, the conclusion was that either of these tools would be suitable for the premachining operation under the given conditions. The operation was approximately 45 percent faster than normally achievable in the conventional production operation. The floor to floor cycle time can be improved with equipment specifically designed for this application to eliminate the problems associated with chip handling.

At the start of the program, the depth of cut was set at 0.030 inch for each pass of the premachining operation. Two passes were required to bring the blank to its final dimension.

1st pass (blank diameter 1.240 inches) to 1.180 inches diameter
2nd pass (blank diameter 1.180 inches) to 1.125 inches diameter

Among some of the final testing performed was the machining of the blank from the original diameter of 1.240 inches directly to the final diameter of 1.125 inches in a single pass.

During our machining trials, a change of procedure was instituted in the M833 program resulting in a new final diameter of 1.100 inches for the premachined blank. Consequently it was necessary to complete one extra pass to bring the previously machined blanks to this final dimension. Current production processing is being carried out on the Mori Seike lathes using the square tool and turning from the blank diameter of 1.240 inches to its new final diameter of 1.100 inches in a single pass.

TASK C FINAL MACHINING

The current conventional production machining program and tooling, except for the rough nose insert and the O.D. turning insert were used as the starting conditions for this portion of the operation. The O.D. insert was changed to a Sandvik Co. No. PFR8U3 from the standard round tool because of the results experienced in the premachining operation. The rough rear O.D. of the blank was also turned with this same tool. For the following operations: a rough nose O.D.; rough front O.D.; and rough major O.D., the insert was changed to the Excello Co. No SN433-4520, once again due to the results obtained with that particular tool in the premachining operation. Although we did have excellent results with the R-B Tool Co. No. PD2-8308 and the Excello Co. No. SN433-4520, it was decided to change to our stock CB047 tool because of its availability and the fact that it worked as well as the others.

As in the premachining operation, various speeds and feeds were tried to obtain the optimum results for each tool. This information is detailed in Table 3. The sequence of the machining operation was altered and in some cases the required number of passes were changed for the best results possible. Different insert configurations were tried on the buttress tool, this section being the most troublesome in regard to controlling chip configuration, i.e., long stringy chips.

Several inserts were modified with various amounts of rake angle on the side of the buttress form in an attempt to better the cutting and chip configuration. This did not improve the condition and actually tended to break the inserts more frequently. We had one of the top notch old style buttress tools modified with an EDM'd hole near the tip of the cutting edge and directed the gas flow through it to the workpiece. With this it was hoped we could cool the chip enough to make it break as well as to force the gas through it to direct the chip away from the work area. We had some encouraging results that would merit further study in the future. While this trial was promising, it was not possible to carry through with the approach on all the tools involved. Piping the gas through the turret head in such a manner, would require a very complex system since the head must rotate as well as traverse the length of the piece. Keeping the insert cool is a big factor in extending the life of the tool.

Trials were also made attaching tubing directly to the tool holder to keep a constant flow of gas to the tip. This was to help direct the chip as well as to cool the workpiece and the insert. Because of the machine constraints, we were only able to do this for the buttress tool. This approach did not give the same results as inserts which were EDM'd because the velocity needed was not attainable with this arrangement, but some benefit was still observed. Again, this method justifies some further examination.

From the beginning of the finish machining experiments, there were little or no problems with the rough 4 pitch, undercut, threading or cut-off inserts, even with increases in the feed and/or speeds. The use of the square tool for O.D. turning proved to give the best results for inert gas machining.

While most of the machining problems occurred with the buttress insert, changing the sequence to rough front and rear 8 pitch, finish front and rear 8 pitch and then finish turn 4 pitch using three separate inserts proved to eliminate most all of the problems. The actual machining portion of the cycle was comparable to current conventional production methods using liquid coolants. However, the awkwardness of handling the bars as well as having to clear the chips and push them down the chute extended the floor to floor cycle time considerably. This was the most common and most difficult problem in the operation. This condition was further exacerbated by the steadyrests and the tight confines of the inner chamber.

Under the normal conditions of conventional liquid coolant machining, the chips from the buttress forming tool either flow down or are washed down to the chip conveyor with little difficulty. With the conditions under which we operated our inert gas machining the chips hit the top of the small inner enclosure and were promptly directed back to the workpiece and proceeded to wrap themselves around the bar. This occurrence slowed the operation considerably because it was necessary to clear the chips completely before continuing. This was sometimes done with great difficulty because of the tightness of the wrapping and the awkwardness in reaching them from the outside of the larger enclosure by means of the long rubber gloves. This problem of the chip wrapping also caused difficulty with the inserts sometimes resulting in premature breakage. Necessary tool changes by means of the rubber gloves were on occasion as difficult to accomplish as clearing the chips.

TASK D PRODUCTION PROVEOUT

Having completed the machining trials as previously described, the data was tabulated and submitted to the PCO with a request for approval to proceed to the production proveout section as called for under Task D.

While this portion of the program deals specifically with the production parameters of machining under a protective atmosphere as established under Task C, there is, as well, a secondary function of supplying chips from both the premachining and final machining operations to be used in Task E for remelt evaluation.

As directed in the contract, a series of 6 standard production melts, containing no remelted chip material, were processed in accordance with the specifications for M833 penetrators. Two of the melts were rejected, one for chemistry and the second to heat treating failure. The standard process

sheets covering the entire procedure from the initial reduction of the DU derby through to the finished operation are illustrated in Figures 12, 13, 14 and 15. The finished penetrators produced from these melts by atmosphere assisted machining will be entered into the production stockpile. As was noted, the machine chips generated during the operation were collected under protective cover to be processed for remelt.

The M833 blanks were prepared in the normal manner in that they were faced and center drilled on the Jones and Lamson (J&L) end working machining. These blanks were then delivered to the specially prepared J&L lathe with all further work carried out under an argon atmosphere.

The protective atmosphere was provided by both nitrogen and argon gas. The argon was used in the small inner machining chamber and the conveyor system. Argon was originally piped into the outer chamber as well, but due to the high leak rate of this section, the low oxygen levels that were desired could not be maintained. Therefore, nitrogen was used to replace the argon in the large outer chamber, where there was no machining performed, as such, an occasional chip escaping from the inner chamber would ignite if there was no protective atmosphere present. Those chips that did escape were not collected for use in the remelt program. In the early stages of the machining trials, nitrogen was used while we were setting up the program because of its lower cost in relation to argon. Chip samples were sent for analysis of the nitrogen levels. The resulting figures of 5 - 6 ppm were less than some of the values obtained from chips generated by conventional production machining methods.

The proveout machining phase began with the four melt lots. Near the completion of the second lot, an accident occurred which resulted in a small fire in the machine. The accident was caused when a new operator was in the process of setting up with new tooling. The main chamber door was open to the atmosphere and he inadvertently put a uranium slug into the chuck rather than a steel slug for indicating. The tool caused a spark which ignited some small chips within the enclosure. The result was the burning of some hydraulic lines which released oil down into the chip conveyor. Water was used to cool the fire which also drained into the conveyor.

Because of the configuration of the conveyor to the main system, it would not be possible to completely remove the oil and water without a major dismantling of the unit. In an agreement with the ARCD, it was decided that, since chips generated under these conditions would be contaminated, the machining under atmosphere would be discontinued.

Having accumulated sufficient chip material to make the required melt from those penetrators which were processed, the disruption did not impact on the experiment. The remaining two lots were completed by the conventional machining method to complete the quantity of penetrators of the program.

Gas usage for the system was measured at the rate of 400 cubic feet per hour of nitrogen which was fed to the outer chamber and 460 cubic feet per hour of argon which was piped to the inner chamber with an auxiliary line feeding to the lower portion of the conveyor. These rates are for a single shift operation which includes the productive machining time as well as the down time required for chip clearing and tool replacement. Again, these interruptions had a marked effect on the processing rate.

The actual yields of the production effort were not impressive. The first lot yielded only 35 percent acceptable penetrators. This was due mainly to the inability to prevent chips from wrapping around the bar as discussed in Task C. The yield on the second lot was much improved, 76 percent, but the processing was slower due to the many times the machine was stopped, either to clear chips or change inserts. Penetrators were able to be reworked to increase the yield.

The start up of the production proveout machining operation is the same point at which the chip compactor came into use. Because of the weight of chips that are required from the premachining operation for a melt, it was necessary to process two melt lots at a time. Each melt lot yields approximately 100 penetrator blanks.

It is not deemed practical to attempt to equate gas usage to a per penetrator rate for this experiment. It was necessary to maintain a constant gas flow to hold the required levels. The slow rate of machining when added to the other functions of the operator such as changing the gas tanks and inspecting the individual parts therefore resulted in a much higher gas usage.

When the operation was first underway, the chips were carried under an argon atmosphere by the conveyor to the discharge chute and into the compactor. The packing die was charged and pressure applied to make the briquette. This first briquette was formed and ejected properly; however, the chips for the second compact galled on the side wall and the piston rendering the unit useless.

An alternate procedure to replace the disabled compactor was approved by ARDC so as not to delay the program. Further discussion of the problem is addressed under Task E.

TASK E EVALUATION OF BRIGHT CHIPS

The DU chips generated in Task D, the production proveout section of this program, were the source material for the recovery melt.

Based on calculations and our own experience, the amount of recoverable chips produced in the premachining and final machining operations of the M833 penetrators represents approximately 20 percent of the melt. Of this amount, 30 percent is generated in the first stage and 70 percent in the final stage. Using these values as a guide, it was decided that this same relationship would be used when addressing chip recovery melts. In this task, the melt consisted of DU derby produced by Carolina Metals, Inc., a division of Nuclear Metals, Inc., titanium sponge for alloying and the briquetted chips.

As was briefly mentioned in Task D, a problem developed with the compacting unit designed and built by South Creek Industries. Chips generated in the first operation, namely the premachining step, were carried by the conveyor, under atmosphere, to the discharge chute and then to the compactor without problem. The packing die was loaded and 4500 PSI pressure applied to the ram. After reaching the full pressure and holding, it was released allowing the base block to slide out sideways out of position permitting the second stroke of the ram to eject the compacted chips. The first briquette was of

good quality with clean edges and had a calculated packing density of 35 percent. The compactor was then repositioned for a second charge. The chips were loaded as in the first instance and pressure applied. Observing the operation, it appeared that the ram did not have the same forward travel although the pressure gage indicated that compaction had taken place. Upon disassembly of the forward section, we found the chips had galled both the inner liner of the die and the surface of the ram to a degree where retraction of the ram was extremely difficult. Therefore, it was no longer possible to consider a compacting operation that could be accomplished under an inert atmosphere within the scope of the contract.

ARDC was advised of the situation with a request that the compacting be carried out using the method developed by Nucelar Metals, Inc. on a previous chip recycle program. This method involves the use of a DU lined packing die 4.2 inches in diameter with a hardened ram having a DU face. The compacting was to be done on a 200 ton vertical hydraulic press. Chips are manually loaded into the die and the charge then preloaded to 50 tons. This step is repeated 3 or 4 times and from experience we know that when full pressure is applied a briquette of approximately 6 pounds having a density of 35 to 40 percent will be produced. Immediately after compacting the chips were stored under vacuum to prevent deterioration and for safety reasons according to Nuclear Metals' rules for handling chips.

This change in procedure was approved by the ARDC Project Engineer. The collection barrel was reinstalled at the discharge chute of the conveyor and the chips were thereby contained under an argon atmosphere. It should be noted that the only time either the chips or the finished briquettes were exposed to air was during the compacting operation and the transfer and loading of the furnace. This did not generally exceed one hour at the end of the workday.

To accumulate the required amount of chip material for the melt, it was necessary to process two lots of penetrator blanks. Upon the collection and briquetting of chips from the two steps of the machining operations, the melt charge was assembled according to the following formular.

Melt No. M-42 (UX-18089) consisted of the following:

DU Derby	1379.0 pounds	=	79.39%
Premachine chips	103.4 pounds	=	5.95%
Final Machine chips	244.2 pounds	=	14.06%
Titanium sponge	<u>10.5 pounds</u>	=	<u>0.60%</u>
Total	1737.1 pounds	=	100.00%

Melting of the charge was carried out in a graphite crucible prepared as follows: The crucible was first cleaned with a mechanical rotary brush and vacuumed. It was then preheated and given two spray coats of zirconium oxide and dried under vacuum.

The melt itself is physically assembled by first placing a single briquette over the knockout plug of the crucible and the titanium sponge is poured into the bottom. The DU derby is then lowered onto the titanium. Finally, the chip briquettes are hand packed on top of the derby. In some previous chip

melts made at Nuclear Metals, a graphite plunger was used for mechanical agitation and to force the lower density briquettes below the liquid level. This same procedure was used for this recovery melt. The vacuum system is then pumped down and, when at the proper level, the power is applied. When the melting of the derby takes place, the mechanical agitation is started and the briquettes are then absorbed into the melt. Total time required for melting is approximately 3.5 hours. The charge is bottom poured by means of a knockout plug and results in 9 billets being cast. After cooling and removal from the furnace, the total weight of the castings was 1704 pounds resulting in a melt yield of 98.1 percent. This is equal to the yields of standard production melts in which no chip material is used.

This technique of assembly and melting is identical to that used in the chip recycle study conducted under Contract DAAK10-83-C-0263. In that program it was necessary to prepare the chip material by a combination of washing, screening and acid pickling prior to compacting. The yields achieved were in the range of 94 percent. Chip preparation under this program represented a considerable effort, none of which is required when the machining of the DU is carried out under a protective atmosphere.

The billets cast from this recycle melt were processed according to the standard M833 procedures. This involves extrusion, sampling for chemistry, heat treating, hardness and premachining operations in preparation for ultrasonic inspection. Refer to figures 13, 14 and 15 numbers 9 through 30 inclusive.

One of the more prevalent concerns of recycle melts has been the uniformity of chemistry over the length of the extruded rods. The following Table No.3 gives a clear indication of the narrow range of variation.

Chemistry specifications for the M833 program are as follows: Carbon 80 ppm; iron 50 ppm; nickel 50 ppm; copper ppm and silicon 150 ppm.

A single full length extruded rod was sampled with the results as follows:

	Carbon ppm	Iron ppm	Nickel ppm	Copper ppm	Silicon
Front	30	21	7	5	52
Rear	40	20	7	2	49

Each step of the operation was monitored by the quality control department for assurance that this chip recycle melt conformed in every respect to the "standard" melt so there would be no reservations as to using this procedure in a production mode.

The extruded rods were heat treated to develop the degree of hardness and other properties of the M833 specification. Reference figures 13, 14 and 15 numbers 16 to 30 inclusive. Following this step, the blank is premachined prior to being tested ultrasonically which examines the material for voids and inclusions. Every blank of this melt was examined in the manual mode which enabled the operator to make a visual comparison of the results against what has been established as acceptable standards.

In the case of this particular melt, there was one reject piece. This was caused by a machining defect and not by a void or inclusion. Therefore, the results established that in this case the quality as indicated by ultrasonic inspection were equal to or slightly better than standard production material. While this data base is insufficient to evaluate projected yields of melts incorporating "bright chips", we can conclude that chips produced by atmosphere assisted machining are suitable for remelting at levels up to 20 percent of the total melt.

CONCLUSIONS

MACHINING

The experimental work conducted under this program has demonstrated that it is possible to machine depleted uranium penetrators of complex configurations in an inert gas atmosphere. Tool life, machine speeds and feeds were equal to and, in some instances, better than the values normally obtained with a conventional, liquid cooled CNC operation, with the added benefit of quality chip recovery.

There were, however, conditions with the conversion of the lathe which impacted greatly on parts handling and chip flow. The end result was an output of about 50 percent of the normal rate of a conventional production machine. Upon the completion of the machining operations, the lathe was cleared of all modifications to return it to its original production status. At this point, it was discovered that there were many more areas from which the gas could leak than had been determined when the enclosure was first designed. These escape routes would, of course, impact on the gas usage figures which were measured during the operation. It is felt that the cost to modify this type of existing machine, or any other like it, would be of monumental proportion and that the result would be better and ultimately less expensive to specifically design and build a machine for this particular application. Several machines have been built recently by the Pneumo Precision Co. of Keene, New Hampshire for the two DOE facilities located at Rocky Flats, CO and Oak Ridge, TN for the very purpose of machining in a controlled atmosphere of nitrogen.

A new machine designed for operation with an inert gas atmosphere would, in the process, have to address the problems of the free flow of chips as against the encumbrance of the small enclosure under which we operated. Air tightness of the chamber in such a new design would also permit the re-examination of the possibility of purification and recycle of the inert gas. The original examination of this possibility determined that it was not economically feasible for such a small operation as would be carried out under this program. Should a more intense effort be proposed, it could again be given serious consideration.

With the incorporation of technical advances such as automatic tool changers, tool probes to assure that the tool which has been changed is properly positioned to produce a part within specification and automatic loading and unloading capability, the machining operation would be greatly enhanced in improving floor to floor cycle time. As we have determined, high pressure gas when directed at the point of the tool assists in breaking the chip and clearing the work area.

Having these advantages within the machining enclosure would permit multiple shift usage before requiring opening of the chamber to the atmosphere. All of the foregoing obviously would impact on the economics of conversion to an inert gas machining procedure.

EVALUATION OF BRIGHT CHIPS

While we experienced difficulty with the automatic compacting of the chips while under a protective atmosphere, closer examination of the problem suggests the basic idea to have merit and that it was a tooling problem which was mostly at fault. The failure to at least have a hardened die liner and ram allowed the chips to freely cut into the material and seize. It was suggested early in the program that consideration be given to a DU lined die and ram face based on our own experience with chip packing. While the DU liner will prevent any iron pick up on the chips, it would not necessarily prevent seizing. However, any scoring of the liner or the ram face would not present any major problems.

Because we were faced with this problem, the ARDC did approve our packing of chips in air, to be followed by storage of the briquettes under vacuum to maintain the overall integrity of the material. The high recovery yield of the melt indicates that a short time exposure to atmosphere does not appear to have a detrimental effect on the raw chips. A closer examination of the method of chip compaction should be considered before any judgement is made requiring a packing station at each production machine.

The quality of the chips with which we worked was good. We encountered no problems with what has been termed as fines and generally considered as unusable.

The melting of the chip compacts in the manner described in the test was completely successful. This can be attested to not only from the high yield of the melt, but also by the results of the ultrasonic testing indicating an absence of voids and inclusions. We therefore suggest that machining of DU under an inert atmosphere did produce chip material of such quality as to be recoverable within the scope and experiments carried out under this program.

TABLE 1

SCI Atmosphere and NMI Production Machining Conditions

	RPM	Surface Speed Feet/Minute	Feed Inches/Revolution	Depth of Cut Inches	Metal Removal Lbs/Hour
SCI Low Speed	276	79	0.0155	0.050	31
SCI High Speed	1000	287	0.010	0.050	71
SCI Most Frequent	610	176	0.0155	0.030	41
NMI Premachine Pass 1	850	260	0.017	0.030	64
NMI Premachine Pass 2	950	280	0.016	0.022	46
NMI Roughing Lathe	1250	350	0.012	0.020	40
NMI Finishing J&L	1750	450	0.010	0.010	35
NMI Buttress Grooves J&L	1200	Varies	0.004	---	--

MACHINE OPERATOR: [unclear]

no	date	machine	operator	cut, rev speed	rate of cut	chatter condition	temp. chamber	chip structure	comments
1	3/18	Smith Tool	Premach Blind	1146 .015	17.375	Chatter	-	Chatter	.005 removal in 1 sec. 155. 1st pass tried in chamber for 2nd machine chip longer.
2		"	"	1700 .015		Chatter	-	Chatter	
3		"	"	1700 .015		No chatter		Too hot, blue to purple	Positive press up. Stripped to start & ended for this amount on bar - chip building tried interrupted cut to break chips -
4		"	"	1700 .015		"		Too heavy	
5	↓	"	"	1700 .010		"			Same as above
6	3/19	Smith Tool	"	1500 .012		Some chatter		Small chips	Too hot - bar hot to hold
7		"	"	1500 .010		No chatter		Chips striated	Stripped color - hot bar
8		"	"	1500 .015		Chatter		"	"
9		"	"	1200 .012		Chatter		"	"
10		"	"	1000 .010		No chatter		64 mil chips	"
11		"	"	2000 .010		No chatter		By rd mil chips	Bar still hot. Had to keep chip in bar Very hot chips acted in bar
12		"	"	1050 .012		Some chatter		Large striated	Stripped, closed hole, of 1st pass to 1st chatter
13		"	"	1050 .012		Some chip on chamber		Small	Bar hot
14		"	"	1106 .013		"	150/100°F	2nd pass color	"
15		"	"	900 .017		No chatter	200°F	Good chip	" cast line .007 below
16		"	"	1500 .017		"	"	"	"
17		"	"	1000 .017		"	"	Very good	Too color
18		"	"	1107 .01		"	150°F	2nd - blue 6 to	Not as hot, changed to nitro-en (chpr) purple better, stays in chamber longer
19		"	"	1210 .017		"	175°F	" little lighter	slightly warm. 3rd pass on some edge
20	↓	"	"	1356 .017		Some chip 2nd pass	140°F	"	"
21	3/20	"	"	1356 .017		Chatter both passes	"	"	Somewhat cooler 5th passing
22		"	"	1210 .017		No chatter	174°F	64 mostly brown	Speeds above 1200 begin to develop chatter at .017 IPH
23		"	"	1210 .017		"	240°F	Chips longer bluish in color	Good finish
24	↓	"	"	1210 .017		1st chatter	250°F	"	Bar hot chipped tool 2 pc on edge

Table 2. Premachining Test Data

REWORKED CONTAINER TEST DATA - PAGE 6

Run	Date	Tool name & description	Operation	Feed rate (ft/min)	Feed (in)	Chip condition	Chip carbide	Chip description	Comments
25	3/20	SA 3001 P12-R11	Premachine	17.375	1100 .015	No chatter	210-240°	Long chips Blind hole	Major finish only the slowest feed & speed the chips are longer
26		SA 3001 P12-R11			1600 .014	"	210-177°	Small chips	Finish improved bar bar
27					1100 .016	Chatter		Long blind hole	Chatter edge man. considerably
28	3/21	SA 3001 P12-R11			1200 .014	"	100-230°	Starchy	SA 3001 P12-R11
29		SA 3001 P12-R11			1000 .014	Tr. slight chatter	100-175°	Small chip too co.	"
30					1500 .014	"	170-225°	Some A. starchy	Little better finish much better build up
31					1100 .014	Some chatter		Mostly blue	Much better - tool chipped because of chips in direction
32					1500 .014	"	100°	Long & starchy	"
33		SA 3001 P12-R11			1800 .003	No chatter	230-118°	Long & starchy	Below center .005 2nd pass only .005
34					2000 .003	Slight "		"	Below center .005
35					1400 .007	"		Short stringy	Steady cleaned chatter stops when
36					2000 .003	"		"	"
37					1800 .003	Much "		"	"
38					1700 .004	Slight "		Fine	"
39					2000 .014	"		"	"
40					2000 .004	"		Some slight but	"
41					2100 .004	No chatter		"	cleaner upon 2nd pass
42					2000 .004	"		Small - fine	smaller fine chips here
43					2000 .004	"		"	new cutting edge
44					2500 .004	"		"	"
45					2000 .010	Slight chatter		"	"
46	3/22				2000 .009	"		"	Bar previously cut 1 pass clean up cut
47					900 .009	No chatter		"	"
48		SA 3001 P12-R11			900 .009	"		"	"

Table 2. (Cont'd.) Premachining Test Data

increased run times, 970, 800, & 1000

Run	Date	Insert used or variation	Operations	Feed rate GPM	Time in minutes @ cut	Surface condition	Temp. change	Chip structure	Comments
1	8/16/73	Sandvik Prod. Type 1	Finish	1100/.015	12-275 in	Chatter		Less structure. Lot	is checked with the master machine
2	"	"	"	1000/.015	"	"		Dark purple	program 1.0: success, tooling, feed &
3	8/17/73	"	"	"	"	No Chatter		Stringy	speed. After trying the round tool for
4	"	"	"	"	"	Chatter		"	several plates, we decided to go with the
5	"	"	"	"	"	"		"	square tool that we had such good results
									with it promising.
5	"	CR017-5A Tool	"	900/.009	"	Very little		"	changed to square tool. .. 9000
									although the 1-3 tool ran down and the
									sample 9000-5000 marked as well.
6	8/18	"	"	"	"	"		"	
7	"	"	"	1200/.009	"	No Chatter		"	
8	"	"	"	1200/.011	"	"		"	The square insert was used on the follow-
9	8/22	"	"	"	"	"		"	ing operations - rough 80, rough finish
10	"	"	"	1500/.011	"	No Chatter		"	2. Front 80 & 2 size 80
11	"	"	"	"	"	"		"	Throughout the finish machining trials work
12	8/23	"	"	"	"	"		"	was being performed on the machine to try &
									cool all the tests, this caused much delay
									in our progress.
13	"	WPI137877877	"	900/.009	"	Very little		Good chips cast?	
14	"	"	"	"	"	No chatter except for bottom's		test	Changed to WPI-137 for Fin. 80 & Fin Race
									Refiles
15	8/25	"	"	1000/.009	"	"		"	Changed to P1000 for R. Roundabout

Table 3. Final Machining Test Data

WORKING CONDITIONS 970, 980, 990, 1000

DATE	TOOL NUMBER & DESCRIPTION	OPERATOR	CUTTING DEPTH	FEED (INCHES PER REV)	TOOL CONDITION	TOOL CHANGE	TOOL DESCRIPTION	REMARKS
15 4/75	WPM13749-1033	Finish 2nd	1000/.011	17.375 in				No. did have the usual insert for sampling rear window only
17	"	"	1250/.009	"				There were no problems from the beginning with the feed pitch entered through the control inserts except an old increase in feeds under load.
18 4/78	"	"	1500/.009	"				Most of the problems occurred with the bottom tool, i.e. chatter, chatter, chatter, welding, chipping, tool life, heat buildup
20 4/90	"	"	1500/.009	"				
21	"	"	1500/.009	"				
22 4/30	"	"	1250/.009	"				
23	"	"	1250/.005	"				
24	"	"	1100/.002	"	chipped tool			Stringy, wrapped chatter on severe square tool and WMI22 & WMI23 was to ed grooves
25 5/1	Bottom Insert	"	1500/.005	"	broken tool			determine how fast we could go without affecting surface finish.
26	"	"	1500/.002	"				
27 5/2	"	"	1500/.002	"				
28	"	"	1500/.002	"				
29 5/3	"	"	1500/.002	"				
30	"	"	1500/.002	"				
31 5/6	"	"	1500/.002	"				
32	"	"	1500/.002	"				
33	Modify Bottom	EDT	1300/.005	"				The entire robe on the side of the bottom insert did not improve cutting or chip em- ulsion and broke more rapidly
34 5/8	Rate on sides of bottom for	"	1200/.005	"				
35	"	"	1200/.002	"				
36	"	"	1200/.002	"				
37 5/10	"	"	1200/.002	"				

Table 3. (Cont'd.) Final Machining Test Data

GENERAL INFORMATION, 1952, 1953, 1954, 1955, 1956

Item	Date	Part Name & Description	Operation	Tool, Size & Set	Feed or Limits or Cut	Machine Condition	Temp. Control	Shop Description	Remarks
62	5/31	Butress Tool	Finish Mach.	3300/.0023					
63									
64	6/3								
65									
66	6/4								
67									
68	6/6								
69									
70	6/7								
71									
72									
73									
74									
75	6/10								
76									
77									
78	6/12								
79									
80									
81	6/13								
82		Butress Tool	Butt Window	1250/.003					
83			R. Front Sp	"					
84	6/16		R. Rear "	"					
85			F. Front "	1300/.002					

On a machine built specifically for Atmosphere machining-would alternate a couple of the steadyrests and of course open up the inner chamber to allow chips to get out of the way easier

Same tool as for Finish Sp. Separate insert

Table 3. (Cont'd.) Final Machining Test Data

Table 4. Rod Analysis

Rod No.	Titanium w/o		Carbon ppm	
	<u>Front</u>	<u>Rear</u>	<u>Front</u>	<u>Rear</u>
1	0.72	0.70	30	40
2	0.71	0.71	30	50
3	0.70	0.71	50	60
4	0.71	0.71	60	50
5	0.71	0.72	50	40
6	0.71	0.71	40	60
7	0.70	0.72	40	60
8	0.70	0.73	40	60
9	0.71	0.74	40	50



Figure 1. Rubber Flap Arrangement

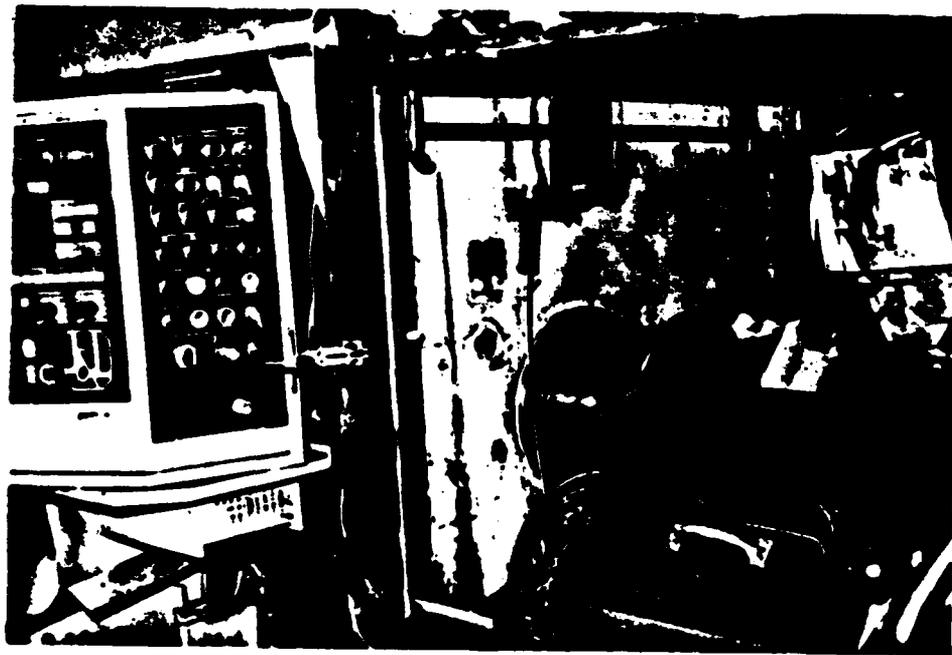


Figure 2. Headstock Enclosure



Figure 3. Tailstock Enclosure

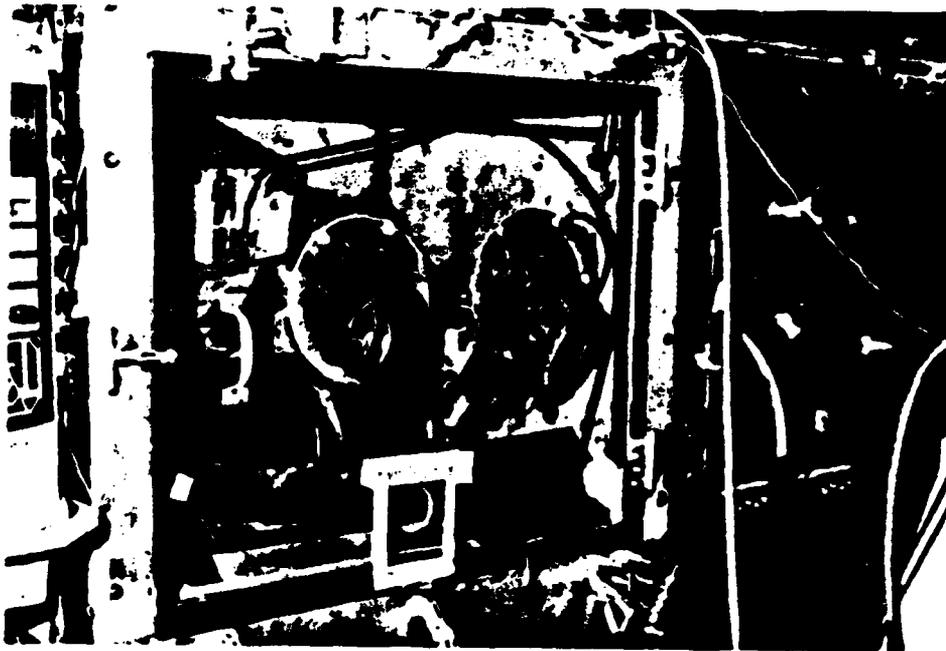


Figure 4. Front Enclosure

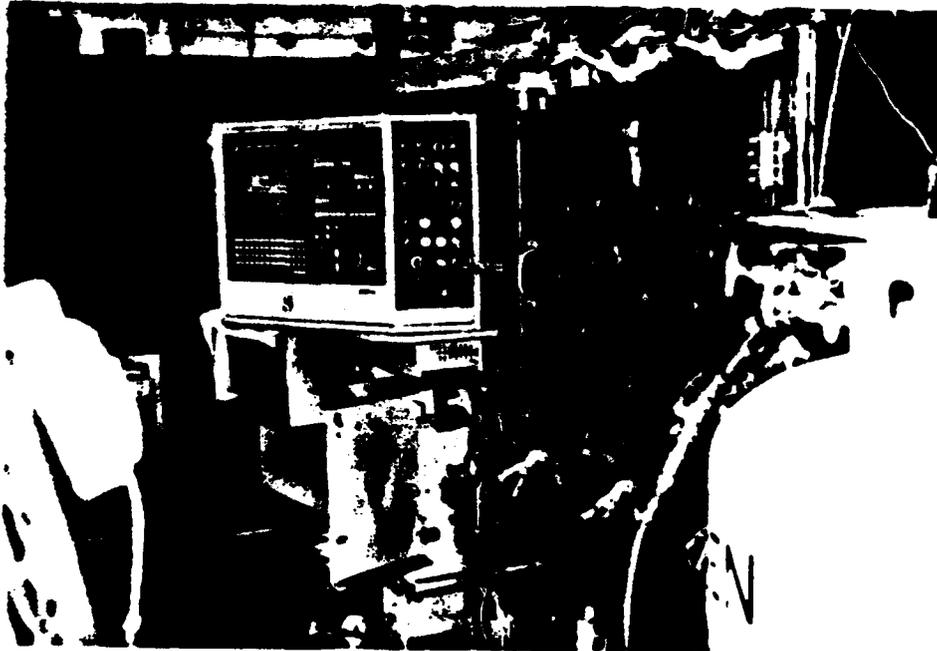


Figure 5. Console and Work Area

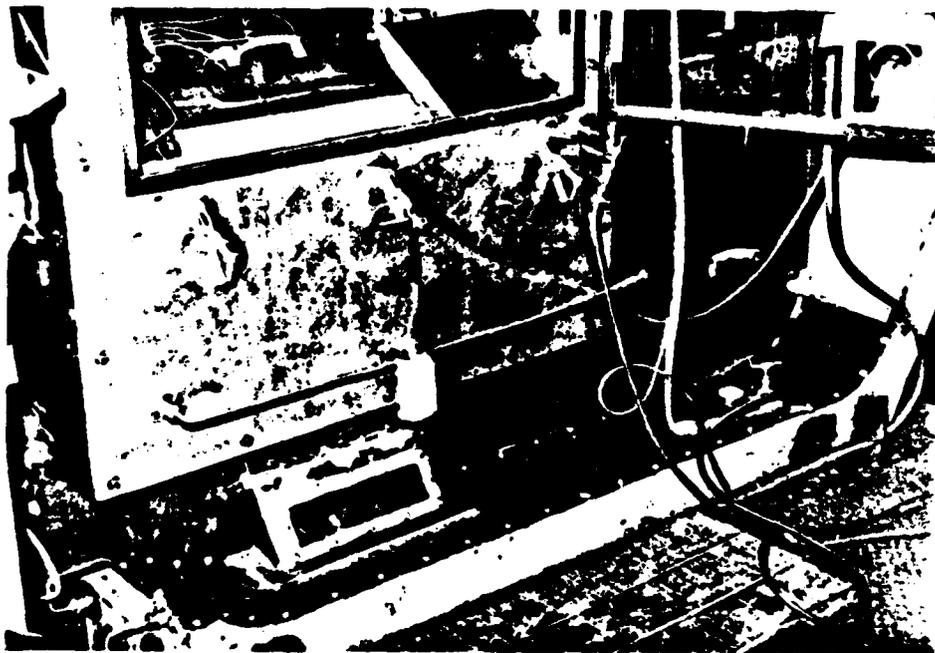


Figure 6. Conveyor Cover

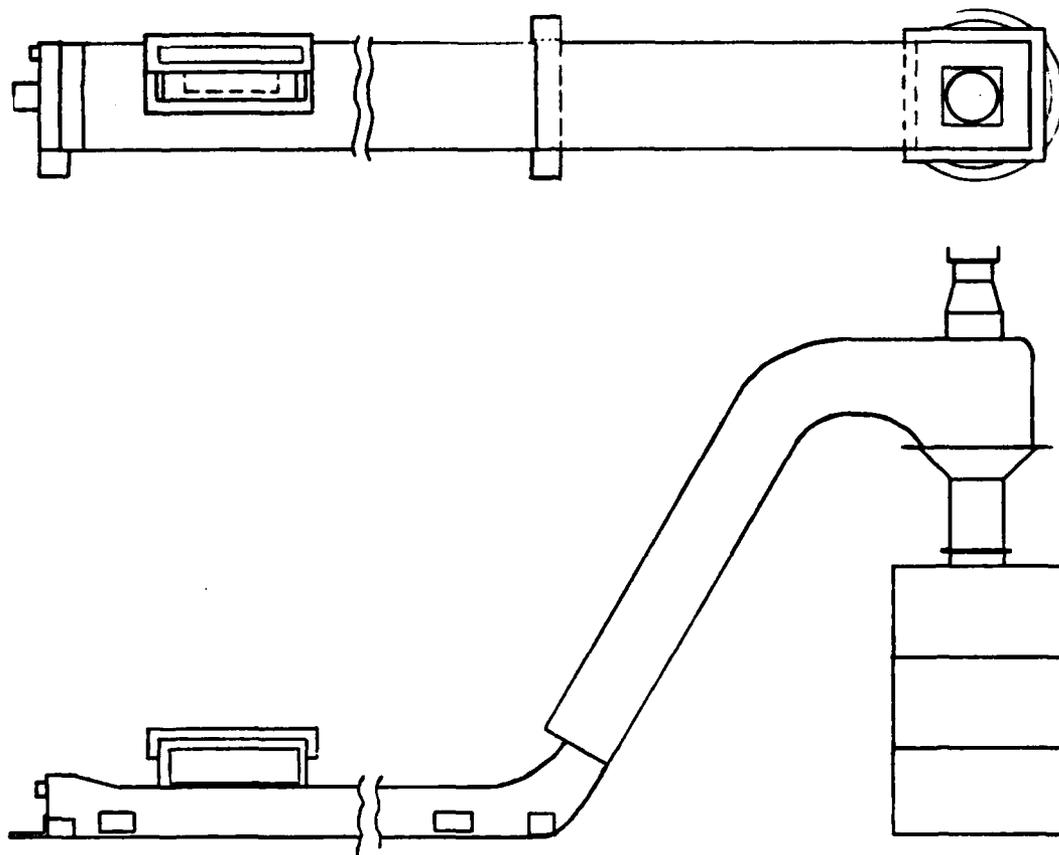


Figure 7. Chip Conveyor

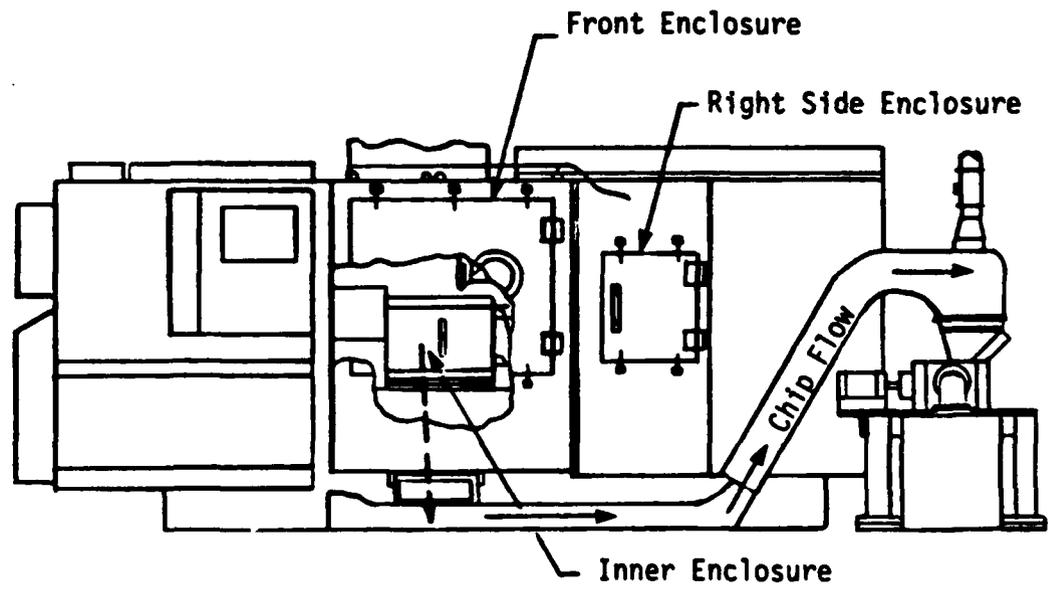
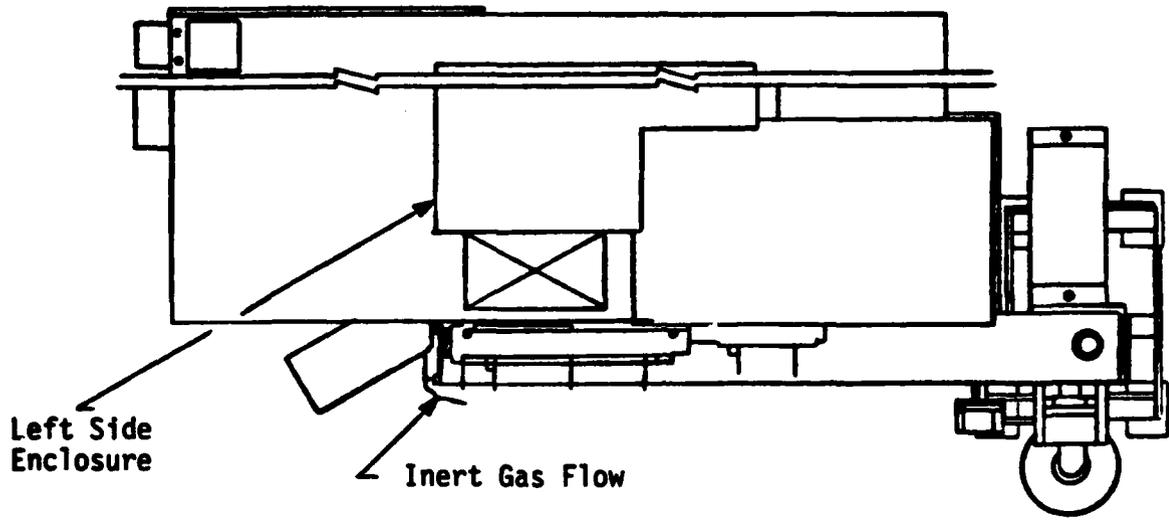


Figure 8. Cutaway Section of Jones & Lamson Lathe

Drawing No.	Assembly	Details
NMI - 000-000	Top Assembly	
- 001-000	Front Enclosure	2, 3, 4, 5
- 002-000	Inner Enclosure	- 001, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16
- 003-000	Chip Conveyor	- 001, 5, 6, 7
- 004-000	Chip Conveyor	- 001, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
- 005	Right Side Enclosure	- 001, 2, 3, 4, 5, 6
- 006	Gas Flow Schematic	
- 007	Left Side Enclosure	- 001, 2, 3
	Sketches	- SX-001-x1, x2, x3, x4
	Total	52 Drawings

Figure 8a. Drawings delivered to NMI by South Creek Ind. Inc.

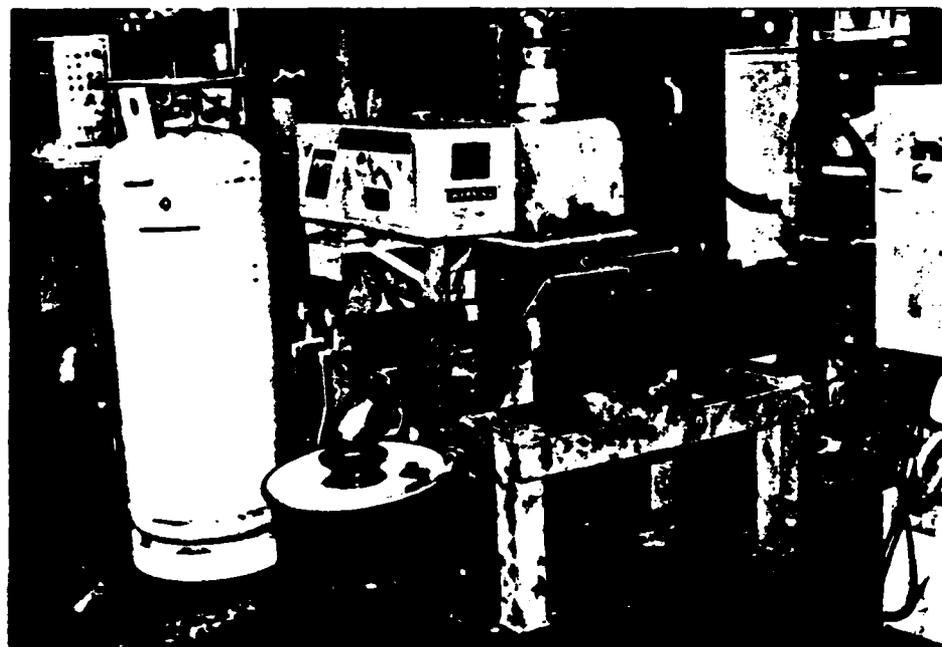


Figure 9. Chip Compactor

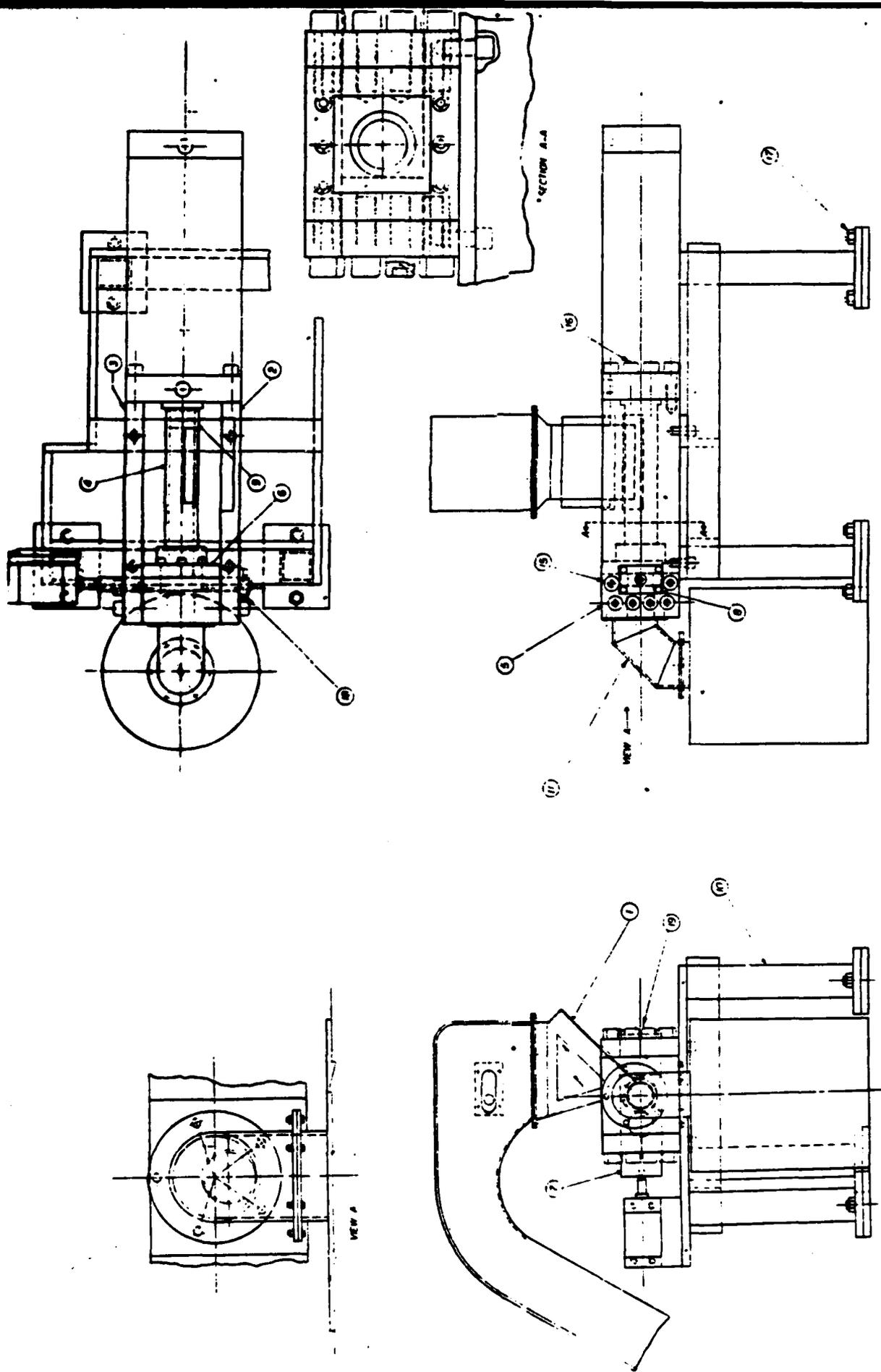


Figure 10. Chip Compactor Assembly

19	CAP SCREW	1	UNBRAKO # 20097 - MSC 32 B
18	CAP SCREW	4	1/2-12 x 1-1/4 LG. SOC. HD.
17	NUT	8	1-8
16	CAP. SCREW	8	UNBRAKO # 20097 H2-20 C 72 B
15	CAP SCREW	12	UNBRAKO # 20097 H2-20 C 56 B
11	BRIQ. CHUTE	1	NMI - 004 - 011
10	TABLE	1	NMI - 004 - 010
9	ROD CAP	1	NMI - 004 - 009
8	GATE PLATE	1	NMI - 004 - 008
7	GATE	1	NMI - 004 - 007
6	DIE	1	NMI - 004 - 006
5	SUPPORT-END	1	NMI - 004 - 005
4	TUBE	1	NMI - 004 - 004
3	SUPPORT-R.H.	1	NMI - 004 - 003
2	SUPPORT-L.H.	1	NMI - 004 - 002
1	CHIP CHUTE	1	NMI - 004 - 001
ITEM	NAME	QTY	PART NO. OR DESC.
PARTS LIST			
SOUTH CREEK IND., INC.			
100-400			211
1-30-85			
ASSEMBLY - CHIP COMPACTOR			
			DWG. NO. NMI-004-000

Figure 11. Compactor Parts List

STANDARD PROCESS

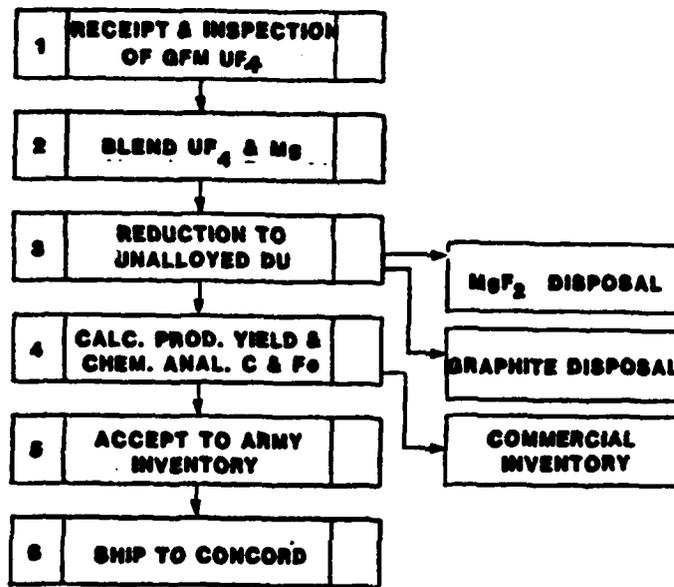


FIGURE 12. PROCESS FLOW CHART FOR DERBY MANUFACTURE

STANDARD PROCESS

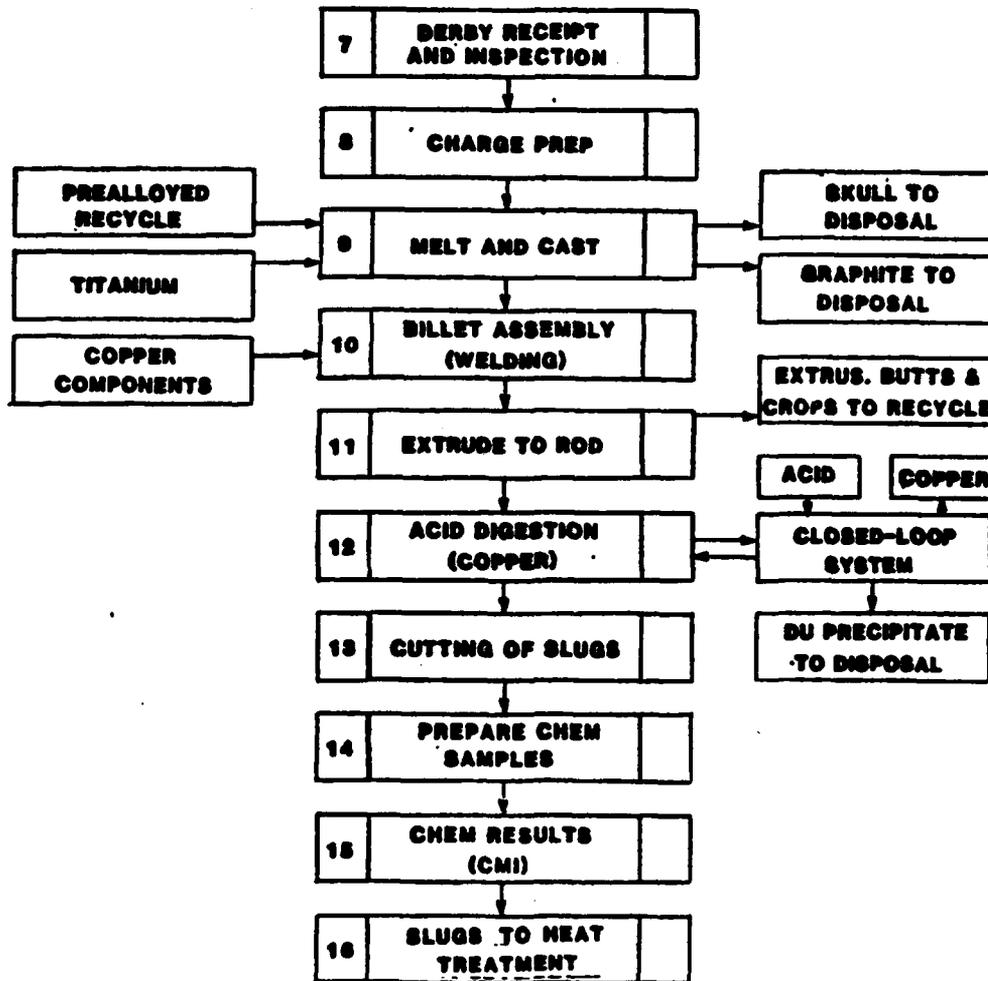


FIGURE 13. FABRICATION OF SLUGS AT NMI

STANDARD PROCESS

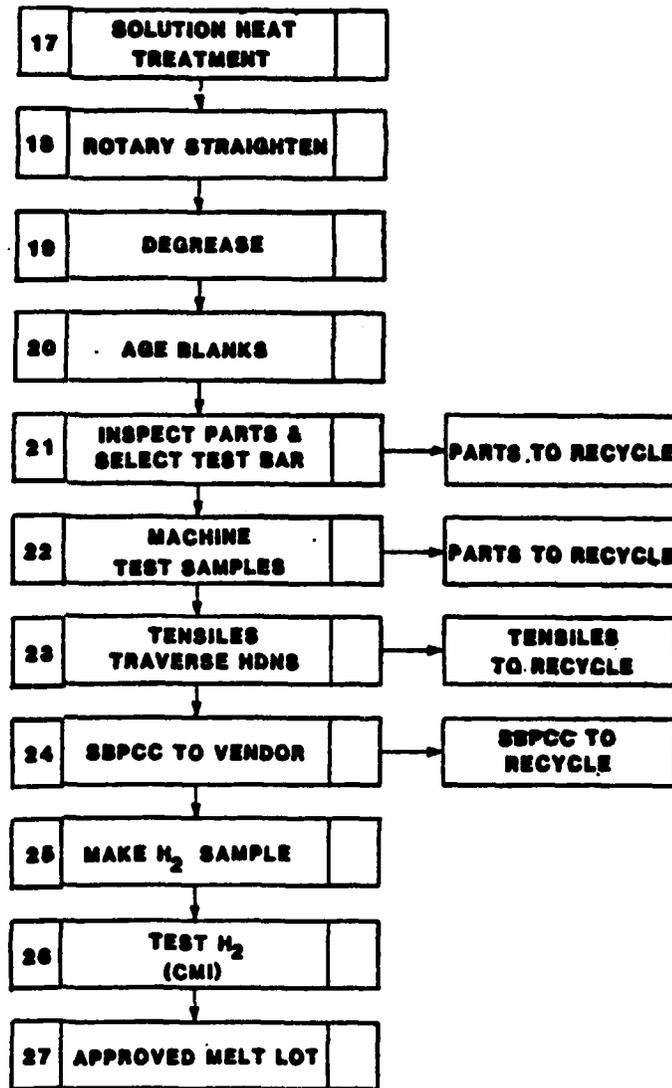


FIGURE 14. FABRICATION OF HEAT TREATED AT NMI

STANDARD PROCESS

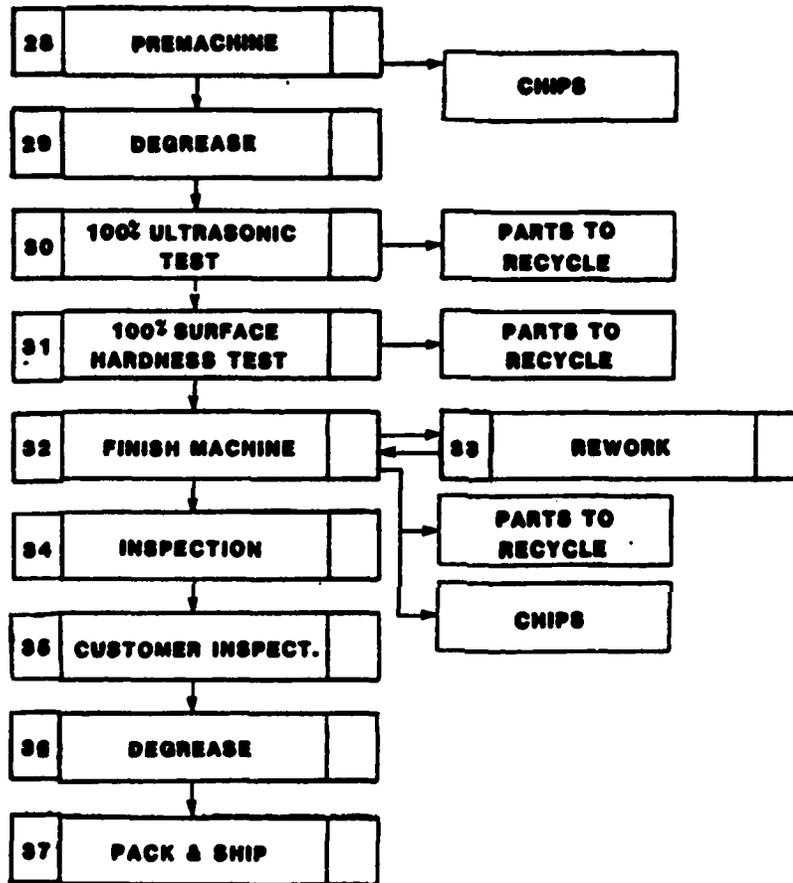


FIGURE 15. FABRICATION OF PENETRATORS AT NMI

APPENDIX A

HEALTH AND SAFETY

This qualitative safety evaluation report has been prepared to satisfy a Contract Data Requirement, for Contract No. DAAK10-84-C-0214.

The safety evaluation conducted as a part of this effort was administered through the Nuclear Metals, Inc. (NMI) Health and Radiation Safety Program. The specific operation/operator(s) was issued a Radiological Work Permit (RWP), in order to identify the actual and potential radiation hazards associated with the particular operation and the precautionary measures (including the use of protective equipment) to reduce the potential for exposure to these hazards.

The safety related facilities and equipment installed to reduce the potential and severity of any hazards occurring from this effort included:

- o A fully enclosed lathe which was continually flushed with an inert gas to reduce the oxidation of the depleted uranium chips and at the same time decreasing the likelihood of a metal fire.
- o Continuous air sampling in the area of this lathe, to detect and quantify airborne concentrations of depleted uranium.

An additional precaution taken to reduce the likelihood of fires resulting from the autoignition of depleted uranium metal turnings was their removal, under atmosphere, at the end of the workday to a remote briquetting station. Following the compaction, which was carried out in air, the briquettes were transferred to our foundry area and stored under vacuum. This type of operation was continued on a daily basis until such times as sufficient material was accumulated for a melt.

In review of the safety related measurements taken during this effort, the data indicates that this method of production does not result in a substantial increase in the airborne concentrations of depleted uranium in the machining area, and that the operators' external exposure was maintained well within established guidelines. The results of continuous air sampling conducted in the machining area and measurements of the machine operators' external exposure were less than 10 percent of our license limit for airborne concentrations and external exposures, respectively.

All procedures, and health and safety related evaluations were conducted in compliance with our Source Material License SMB-179 issued by the U.S. Nuclear Regulatory Commission, dated 23 May 1984.

APPENDIX B

ECONOMIC ANALYSIS

The concept of machining of DU within an atmosphere, specifically argon, has many economic merits to support its implementation; the foremost being the higher efficiency of raw material utilization. The cost savings realized as a result of recycling machined chips versus the cost of collection, processing, and subsequent burial of this material is significant. Current cost data suggest that the upward trend of burial and transportation costs will continue. The efforts to improve methods of collection and processing of waste material has reached a level of near saturation. The study conducted by NMI in conjunction with army personnel under this contract is a positive demonstration of mutual desires to curb cost and increase material utilization efficiency.

The conclusion reached as a result of this study with respect to retrofitting existing facilities, Jones and Lamson lathes, is that it is not technically feasible nor financially prudent to do so. The basic technology of machining within a controlled atmosphere is currently available. Our Manufacturing Engineer assigned to this MM&T has had several conversations with an area machine manufacturer who has built several machines specifically designed to machine within a nitrogen atmosphere. The specifics of the machine are not available; however, the manufacturer, Pneum Precision, Inc. of New Hampshire, suggests that a CNC lathe to machine long rod penetrators equipped with all necessary tooling, probes, tool changers, and designed to machine in an inert atmosphere would cost approximately \$360,000 each. In addition, an external multi-station gas recycling system would be required. Koch, Inc., a manufacturer of this type of system, suggests that a system to handle multi-station recycling of gas would cost approximately \$250,000 and would recycle 90% of the inert gas.

The compact and briquetting of machined chips would utilize the existing machine chip conveyor system to transfer the chips to a central processing point. The production process and facility layout to support the recovery of finished machine chips would consist of four CNC lathes, a chip conveyor system, and a chip compactor of each for two finished machine lines. The implementation of machining of DU under argon with its inherent maximization of material utilization would necessitate that 1,800 pounds of chips be briquetted per production day. The facilitization of the second machine line is not seen as an overkill, rather as a necessity to maintain production flow. The compactor tooling would require a DU liner to offset the potential of contamination. Additionally, a magnetic separator would be required to assure the magnetic metals are not introduced. The cost of the chip compactor, screen, magnetic separator, and one set of tooling should be approximately \$75,000 each.

Lessons learned in the Vacuum Induction Remelt MM&T and the chip melts made on this program point out the necessity of agitation or stirring of chips during the melt. We have experimented with mechanical stirring with a modified graphite "breakoffski rod" shaped with fins which acts as a paddle allowing the molten metal to be stirred. While this form of agitation seemed to be

ECONOMIC ANALYSIS (Continued)

effective, it may not be conducive to a volume production process. We have been advised that electromagnetic agitation of the melt is highly effective and efficient resulting in a much greater level of intermix of the charge. The physical agitation is a result of the direct influence of induced frequency changes starting with 3,000 cycles then reducing to 300 cycles. The power sources required to affect this are commercially available and cost approximately \$30,000 each. All ten of the 14 inch melt furnaces owned by NMI would be modified by replacing the existing power sources with the multi-frequency power sources.

The cost savings anticipated as a result of recycling machined chip would be \$9.577 per core based on a mobilization rate of 10,000 cores per month. This cost savings would not be in effect until all process changes are accepted and the new equipment is on line and fully operational.

Labor	\$10,080
Material	68,564
ODC	53,063
Applicable Overheads	-15,776
Savings at Cost Line	<u>\$95,770</u>
Monthly Production	10,000

<u>Equipment/Activity</u>	<u>Unit Cost</u>	<u>Total Cost</u>
Eight (8) CNC Lathes	\$360,000	\$2,880,000
One (1) Gas Recycle System	250,000	250,000
Ten (10) Electromagnetic Agitators (Melt Cast)	30,000	300,000
Two Chip Compactors w/Tooling	75,000	<u>150,000</u>
Equipment Cost		\$3,580,000
Installation Cost 50% of Equipment		<u>1,790,000</u>
Total Cost		\$5,370,000
Savings Per Core		\$9.577
Break Even Point in Cores Produced		560,718
Break Even Point in MOB Rate Months		56.1

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