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**CONCEPTUAL DESIGN REPORT FOR THE MECHANICAL
DISASSEMBLY OF FORT ST. VRAIN FUEL ELEMENTS**

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ABSTRACT

A conceptual design study was prepared that (1) reviewed the operations necessary to perform the mechanical disassembly of Fort St. Vrain fuel elements (2) contained a description and survey of equipment capable of performing the necessary functions, and (3) performed a tradeoff study for determining the preferred concepts and equipment specifications. A preferred system was recommended and engineering specifications for this system were developed.

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Conceptual Design Report For The Mechanical Disassembly Of Fort St. Vrain Fuel Elements

1. INTRODUCTION

The Fort St. Vrain (FSV) Reactor, a High Temperature Gas-Cooled Reactor (HTGR), operated from 1979 until its shutdown in August 1989. During decommissioning, Public Services of Colorado shipped several irradiated fuel elements to the Idaho National Engineering Laboratory (INEL) for storage. Each graphite fuel element has a hexagonal cross section and has 210 holes loaded with fuel, 6 holes loaded with burnable poison, and 108 through drilled holes for coolant flow. To reduce the volume of high level radioactive waste, the spent fuel must be removed from the graphite fuel element.

As a part of their destructive examination program, General Atomics Technologies, Inc. (GA) removed fuel compacts from an irradiated fuel element^a manufactured from H-327 nuclear grade graphite. The element contained both fuel cured prior to being irradiated (CIB) and fuel cured in the element during the irradiation cycle (CIP). Swelling of the CIP fuel caused some problems with the removal process; however, standard FSV fuel of the cured in bed (CIB) type was easily removed. Experience gained by GA during their studies was given consideration in this investigation of possible disassembly methods.

This report provides a description of a concept for mechanically removing the fuel compacts from the graphite fuel elements. Also included in this report is a description of a disassembly method, survey results of available equipment, and specifications for recommended equipment and tooling designs.

1.1 Scope

This conceptual design study includes a review of the operations necessary to perform the fuel removal, a description and survey of equipment capable of performing the necessary functions, and a tradeoff study for determining the preferred concepts and equipment specifications. This study also includes cost and availability information.

^a Destructive Examination of Fort St. Vrain Fuel Test Element FTE-2, GA-1485, Rev 10/82

1.2 Requirements

The requirements for mechanical disassembly of Fort St. Vrain fuel elements are documented below. The machine capability requirements and system component requirements are specifically listed. The design assumptions are also documented below.

1.2.1 Machine Capabilities

The fuel disassembly system must:

- A. Have capability to remove fuel from the following three standard fuel block configurations (1) standard fuel element, (2) control fuel element, and (3) bottom control fuel element
- B. Have the capability to verify all fuel compacts have been removed from the block
- C. Have the capability of applying to the fuel compacts a removal force up to 25 lb in a nominal mode or 150 lb in an override mode. Visual indication must be provided when the machine is operated in the override mode. Override mode shall be initiated manually
- D. Be capable of monitoring and controlling the magnitude of the force applied by the compact removal tool
- E. Include graphite chip and dust removal capability with adequate filtration and collection
- F. Be capable of removing fuel from at least two blocks per 8-hr shift
- G. Be capable of collecting all fuel compacts and fuel particles removed from the elements
- H. Be easily adaptable to a hot cell
- I. Be computer controlled with operator override capabilities.

1.2.2 System Components

Requirements for the system components are listed below.

- A. Electrical components must be sealed or air purged to prevent exposure to the conductive graphite dust.
- B. System components must exhibit high serviceability and durability.

- C. Enclosed electric motors must be explosion proof.
- D. Lubricants such as oil and water must not be used (sealed bearings excluded).
- E. Decontamination requires the use of 0.1 molar nitric acid. All exposed system parts must tolerate exposure to this solution without damage
- F. Equipment must be commercially available and adaptable to remote operation and maintenance.
- G. Either electricity or pneumatics may be used to power the system equipment.

1.2.3 Design Assumptions

Design assumptions for the mechanical disassembly of the FSV fuel elements are documented below.

- A. All neutron sources have been removed from the graphite blocks.
- B. Burnable poison holes contain compacts with boron particles; therefore, these compacts must be removed from the fuel element.
- C. Unsuccessful attempts to remove fuel compacts in the override mode will be considered as a special case and will not be covered by this design.
- D. The radiation field of a loaded fuel element is approximately 1500 to 2000 rem at 3 ft in the air.
- E. Small amounts of graphite mixed with the removed fuel is acceptable.
- F. Quality Level B (Level II) requirements are applicable to this work.

2. METHOD OF DISASSEMBLY

To remove the fuel compacts from the fuel element, the block must first be identified as one of the following types of elements:

- Regular fuel element
- Control rod element
- Bottom control rod element

and its position relative to cutting and removal equipment must be verified. Next, the fuel holes in the block must be exposed. This involves repositioning either a cutting head or the workpiece. The fuel pellets must then be extracted from the block. During these operations, a mandatory requirement is that the working environment must be kept clean by removing the graphite dust and chips generated by any cutting process.

Automating this process requires that these operations be controlled and interfaced by employing a computer operated system. The fuel disassembly operations or processes are shown graphically in Figure 1.

The following sections of this report define the four processes involved in fuel element disassembly and removal and identify possible methods for performing each. These four processes are the (1) verification process, (2) fuel exposure process, (3) dust removal process, and (4) fuel removal process. Advantages and obstacles for each method are examined, and a preferred method is recommended.

Figure 1. Fuel element disassembly processes

2.1 Verification Process

The fuel disassembly system is required to handle three different types of fuel elements. They include: (a) regular fuel elements, (b) control rod fuel elements, and (c) bottom control rod fuel elements. The equipment must be able to identify and/or verify the block type before initiating the fuel exposure process. It is also necessary to verify the elements position relative to the exposure equipment and make adjustments in its alignment. Another important verification task is to ensure that the fuel is actually removed during the removal process. These three key features are addressed in the verification process.

2.1.1 Verification of Fuel Element Type

Figure 2 shows a cross section drawing of a standard fuel element. The fuel elements are 31.22 in. long and have hexagonal cross sections that measure 14.17 in. from flat to flat. The fuel is contained in an hexagonal array of 0.500 in. diameter blind holes drilled parallel to the fuel element axis and surrounding the coolant flow channels. The fuel holes are drilled from the top of the element to a depth that leaves a minimum of 0.25 in. between the hole and block bottom face. The fuel compacts are stacked in the fuel holes and graphite plugs are cemented in the hole openings at the block top face. These plugs are 0.250 ± 0.001 in. thick and approximately 0.500 in. in diameter. Each standard fuel element contains 210 fuel holes, 108 coolant holes, which are 0.625 in. in diameter except for the six 0.500 in. holes surrounding the fuel handling hole, and six 0.500 in. diameter poison holes.

Control rod fuel elements are similar to the standard fuel element, but contain three larger diameter holes for control rods and reserve shutdown material. The two control rod holes and the reserve shutdown hole are 4.00 in. and 3.75 in. in diameter, respectively. The control rod elements contain 120 fuel holes, 57 coolant channels, and six poison holes. Figure 3 shows a diagram of the control rod fuel element.

Similar in cross section to the control rod element, the bottom control rod fuel element extends about 7.5 in. below the core, hence the fuel holes in this element are only 21.70 in. deep. The reserve shutdown hole is also 21.70 in. deep. Figure 4 is a cross section of the bottom control rod fuel element.

Figure 2. Schematic of regular fuel element.

All three block types have three graphite dowels on their top face and dowel receptacle holes on their bottom face for aligning the fuel elements as they are stacked in a column to form the reactor core. The dowels are threaded into the graphite element and cemented in place. An array of six fuel holes are beneath each dowel. Owing to the dowel placement, the bottom and top of the fuel holes in this location are at a different elevation than the surrounding holes.

The difference in physical features of the fuel elements makes it relatively easy to distinguish one type from another. Methods of element identification and verification include visual inspection and inspection with a surface scanning device.

Visual inspection might be accomplished by using a camera and visual monitor . The camera may be mounted on a manipulator arm and positioned to view the distinguishing block features. An operator at the monitor would then record the block type and initiate the appropriate machining sequences. This method may require an additional manipulator, and positioning of the camera could be restricted by other equipment in the vicinity of the element. Such a system suffers from the inability to automatically record the identification of the fuel elements and subsequently initiate the corresponding machining processes; however, its function might be ideal if a redundant verification is required.

Using a sensing probe to scan the fuel element faces for identifying features has the advantage of automatically recording the fuel element identification and initiating the proper machining process. As will be demonstrated in the following sections of this report, a sensing probe, which is shown to be a necessary design feature, can be an integral part of the fuel exposure equipment.

2.1.2 Verification of Fuel Element Alignment

Element alignment may also be verified by the methods described for element identification i.e., visual and using a sensing probe. The visual system may not be accurate since it is performed by operator observation. Additionally, visual alignment would require manual manipulation to achieve proper placement and workpiece alignment. However, if the sensing probe were operated by the same Computer Numerical Controlled (CNC) controller as the cutting device, this method would be as accurate as the machining process, and feedback to the computer could automatically compensate for any misalignment. The sensing probe is considered to be the best option for verifying and compensating for block alignment.

2.1.3 Verification of Fuel Compact Removal

Either the visual method or sensing probe method could be employed for verifying that the fuel compacts have been removed from a fuel hole. The same shortcomings apply to the visual system in this application as previously noted in the other verification operations. However, a sensing probe could be inserted in the alleged vacant fuel hole and pushed the entire hole depth. If nothing was sensed by the probe, the hole would be declared clear, and the fuel removal would be verified. This type of probe verification could be an integral part of the fuel removal process if the sensing rod was used to push the fuel compacts out of the fuel holes.

Figure 5 is a decision tree outlining the advantages and disadvantages of the various verification methods. The preferred method is highlighted, i.e., the sensing probe.

Figure 5. Examination of verification methods.

2.2 Fuel Exposure Process

Before the fuel compacts can be removed from the fuel element, the ends of the fuel holes must be opened. Opening the fuel holes requires removing the graphite material between the end faces and the holes. Two methods for opening the fuel holes and their implementation are described in the following sections.

2.2.1 Facing Fuel Element Ends

One method of exposing the fuel holes is to simply face off the material from the ends of the fuel element. This can be accomplished in a number of ways including a milling/facing operation or simply cutting the end of the block off with a saw. Both operations have the disadvantage of generating a large volume of waste graphite that must be disposed of stored. Additionally, the sawing operation would require a device for handling the graphite piece that was cut off.

In their study, GA used a modified band saw to cut a 0.5-in.-thick slab off the top of an irradiated fuel element. The fuel in all holes except for those under the dowel pins was exposed; however, the removed slab not only contained the fuel plugs, but a portion of the fuel compacts was also cut. Apparently, the fuel compacts did not settle in the fuel holes as originally anticipated. Another problem was that the fuel under the dowel pins still had to be exposed. This could not be accomplished by another cut of the band saw because doing so would cut additional fuel off the already exposed fuel holes. GA noted that during the cutting operation the saw blade became dull and required replacement. The saw blade may have been dulled by cutting the ceramic fuel particles or by rotation (rolling) of the fuel compacts.

In addition to their sawing tests, GA also drilled the material at the bottom of the blind fuel holes. The 0.375 in., single hole, drilling device was positioned and aligned using the coolant channels as guides. During their drilling, they discovered that the blind hole depth varied from hole to hole. Since the compact location within the fuel hole is not known and the fuel hole depths vary by nearly 1 in., the facing method of fuel hole exposure is not recommended. Because both the sawing and face milling operations cut to a predetermined depth, the end of the fuel hole may or may not be exposed after the first cut; and it may be necessary to make another cut that may damage fuel in the already exposed holes.

2.2.2 Drilling

Another method for exposing the fuel holes involves using a cutting tool to remove only the graphite material between the element faces and the fuel holes, leaving intact the webbing between holes. This could be done on a hole-by-hole basis with a single cutter, or several holes could be exposed simultaneously using a multiple spindle cutting head. Since the graphite webbing between holes would remain intact, this method would reduce the amount of graphite removed from the fuel element.

The ability to remove material from over several holes simultaneously is appealing for at least two reasons. First, total drilling time and subsequent block processing time would be reduced. Second, tool wear would be reduced since individual cutters are required to drill fewer holes. This would increase the time between tool change out and consequently increase production. Several designs of multiple spindle cutting heads are readily available and can be applied to meet our objectives. However, the disadvantage of such a cutting method is the inability to sense individual hole break-through, resulting in possible fuel damage.

A larger diameter cutter could also be used to expose several fuel holes in a single operation. This idea falls between the end facing and drilling options. It has the advantage of removing less total material than the facing operation and can provide longer tool life over a single cutter by drilling fewer holes. This concept is limited by the same problem associated with the multiple spindle cutters, i.e., the inability to sense individual hole break-through, resulting in possible fuel damage.

Using a single hole cutter would increase the time to expose the element fuel holes and tool life would decrease because the single cutter would be required to drill all holes. However, the advantage of a single cutter is the ability to sense a change in torque when the cutter has broken through the graphite and into the fuel hole. Once break-through is sensed, the cutter can be immediately stopped and retracted, preventing damage to the fuel compact. Tool wear problems can be solved by including an automatic tool changer in the drilling machine design and by using polycrystalline, diamond-impregnated cutters.

A variety of cutting tools are available that could perform the drilling operation. Two cutting tools of interest are an end mill and a coring mill. An end mill would remove all material between the block face and fuel hole. The material would end up in the form of graphite dust and graphite chips. A coring mill would bore around the fuel hole, and waste

from this process would be graphite dust and a plug of graphite. If a coring tool were used, an additional process would be required to remove the graphite plug from the cutter.

Figure 6 is a decision tree outlining the advantages and disadvantages of the various fuel exposure methods. The preferred method is highlighted, i.e., the end mill cutting a single hole.

Figure 6. Analysis of fuel exposure methods.

2.3 Graphite Dust Removal Process

Since the conductive graphite dust has the potential of shorting out an electric motor, and may cause problems to moving devices such as slides as well as being abrasive, the working environment must be kept as free from graphite dust as possible.

A dust collection system is necessary to alleviate these potential problems. The drilling or sawing operation could be isolated from the rest of the system by putting a flexible boot around the face being cut. A vacuum could then be attached to the boot to remove the waste generated by the cutting operation. Another option is to make the dust removal system an integral part of the cutting operation. Gun drilling^b and trepanning^c operations integrate coolant systems with cutters by injecting a coolant through an annulus in the cutter shank. By applying a vacuum to the annulus rather than injecting coolant, it may be possible to use the coolant annulus to remove the dust and chips generated during a cutting operation. Application of an integral system such as this would eliminate the need for a bulky isolation device; however, it would drive the design of the cutting tool.

Figure 7 is a decision tree outlining the advantages and disadvantages of the various graphite dust removal methods. The preferred method is highlighted, i.e., integrate cutter and vacuum.

^b A trepanning drill or a centre-cut drill used for deep hole drilling.

^c Cutting tool in the form of a circular tube, having teeth on the end; the workpiece or tube, or both, are rotated and the tube is fed axially into the workpiece, leaving behind a narrow grooved surface in the workpiece.

Figure 7. Analysis of graphite dust removal methods.

2.4 Fuel Removal Process

Once the fuel holes have been exposed, the fuel compacts must be removed from the fuel element i.e., using methods like pressurized air or a push rod.

Pressurized air could be directed down the exposed fuel hole to eject the compacts. With tool changing capabilities, this method would be relatively simple to implement. However, disadvantages of this method include the inability to control the compact removal speed, and a separate method would be required to verify actual removal.

Alternatively, a blunt end rod can be inserted into the exposed fuel hole, and a force applied to drive the fuel compacts out. This push rod would combine the removal and verification processes. If the rod traveled its full stroke, actual fuel removal would be verified. Furthermore, the rod could also be equipped with a device to sweep loose particles out of the fuel hole. If fission products have leached into the fuel element, a flexible rotating shaft could also be used to ream out the fuel holes. This condition is expected to be an exception; however, the push rod method could be adaptable to provide this function.

The ram tool may be mechanical (rack and pinion), hydraulic, or pneumatic. The mechanical ram has several moving parts; therefore, it may not be as reliable as the hydraulic or pneumatic rams. Since hydraulics are not permitted in this application, the pneumatic ram would be the equipment of choice.

In their tests, GA found that on the average a minimum pushing force of 2 lb was required to remove the fuel compacts. However, monitoring of ram position and control of the pushing force applied by the ram is necessary in the event of an abnormal condition.

Figure 8 is a decision tree outlining the advantages and disadvantages of the various fuel removal methods. The preferred method is highlighted, i.e., the pneumatic ram.

Figure 8. Analysis of fuel removal methods.

3. SURVEY OF DISASSEMBLY EQUIPMENT

This section of the report provides the results of a survey of the equipment that could be used to perform the processes previously described. Catalog cut outs of a sample of available equipment were assembled and are presented in Appendix A. Three options for equipment selection were considered. First, a component-based system that is put together piece by piece; second, a system that is a single entity and is self-contained such as a machining center; and third, a system that is created from modularized components. Advantages of the component and modularized approach include flexibility and cost.

This section of the report describes the three systems and investigates the equipment required for each.

3.1 Component-Based System

A component-based system would be comprised of individual pieces of equipment consisting of drilling and pushing devices, workpiece table, linear translation stages for positioning either the workpiece or tools, sensors, and a control system. The individual components would be mounted to a structure made to accommodate the fuel element. Since remote disassembly is required, the control system would position and control the translation stages, drilling operation, and fuel push-out operation. The advantage of such a system is total flexibility; however, interfacing the control of all equipment could be complex, resulting in some difficulty.

The basic layout of this system is shown in Figure 9. In this design, both ends of the fuel element are drilled simultaneously by pneumatic or electric drills. After exposing the fuel, the workpiece station is rotated 90 degrees, and a pneumatic ram is used to push the fuel compacts out of the graphite fuel element. Such a system would require the drills and perhaps the ram to be mounted on linear translation stages. Additionally, the workpiece table would require three axes of translation and rotational capability. These positioning devices would be moved by servomotors interfaced with a computer system. Air flow-to-pneumatic devices and signals to the electric equipment would also be controlled and monitored by the same computer system.

A survey of equipment comprising the component-based system is presented in Sections 3.1.1 through 3.1.5.

Figure 9. Schematic of component based system.

3.1.1 Drilling Devices

Many drilling devices are available; however, only two drilling units were investigated. One was electric powered and the second was air driven. Both units are relatively compact and capable of driving a single cutter or a multispindle cutting head.

A pneumatic drill manufactured by Sugino Corporation has a fully automatic and adjustable rotation speed and feed rate. The company also provides the hardware necessary to remotely regulate the feed and recoil motion of the drill. This hardware must subsequently be interfaced with the Computer Processing Unit (CPU) for control and data acquisition.

An electric drill manufactured by Suhner also has adjustable drill rotation and feed rate. Remote control of the unit is achieved through the use of pneumatics. The feed rate is controlled by admitting air to, and venting it from, a built-in cylinder that drives the shaft. Air to the drill feed would subsequently be controlled by solenoids. To reverse direction of the drill, a pneumatic valve is used. Total stroke on the drill is restricted by pneumatic or electric limit switches. Hardware to operate and control several units simultaneously, as well as computer interfacing equipment, is also available from the drill manufacturer.

3.1.2 Pushing Devices

Using a pneumatic cylinder as a push rod is the simplest and most direct method being considered for pushing the fuel compacts out of the fuel elements. Pneumatic cylinders have been used successfully on other spent-fuel handling machines. Two cases are the Dry Rod Consolidation Machine and the Aircraft Nuclear Propulsion Refueling machine.

Standard commercial components are available for monitoring and controlling the removal force, speed, and position of the rod. The force exerted by the rod can be monitored and controlled using pressure transducers. The speed for pushing the fuel compacts out, and retracting the rod, can be independently controlled using standard flow controllers. The rod position can be monitored by magnetically-activated switches attached to the outside of the cylinder.

3.1.3 Positioning Devices

Positioning of the workpiece relative to the removal equipment (ram and drills) can be accomplished as shown in Figure 9 or alternately by providing rotation capability to the table and two-axis motion to each piece of removal equipment. Either way, the operating principle remains the same. Each translation slide or axis of motion is supplied with a rotary servomotor and conventional ball screw drive. Optical encoders are used for position feedback. Servo controllers and Personal Computer (PC) interfacing hardware are also commercially available.

Positioning equipment investigated from two companies was essentially the same. The Anorad Corporation provided a concept for the necessary motion devices as outlined in Figure 9. They recommended seven axes for translation and an additional axis for rotation. Their concept included all hardware required for interfacing with a PC.

3.1.4 Process Control Equipment

Process control equipment would include the computer to monitor and direct the process as well as special computer cards or a data acquisition system to complete the interface between the computer and equipment. A multitude of such systems exist with a variety of features.

3.1.5 Sensors

Flow and pressure sensors, as well as controllers, will be necessary if pneumatics are used. Flowmeters will be required to monitor drill speed and feed rates, and a pressure gauge will be used to monitor the ram pushing force. Solenoid valves will control the air flow. Using a parallel controller card or data acquisition system, these items can be readily interfaced to a computer.

3.2 Machining Centers

Vertical and horizontal milling machines have evolved into computer controlled machining centers. The typical machining center is totally enclosed and self-sustaining. A part is placed in a loading bay, and the computer programmable milling machine does the rest. Features include multiaxis motion, position and dimension sensing probes, tool changer, and computer interfacing. These machines are built for high production precision machining.

Application of such a machine to the fuel disassembly work would be feasible, but may not be the most effective since the machining centers offer capabilities far beyond those necessary for the fuel disassembly work. Literature from two companies that supply machining centers are included in Appendix A. The cost of a machining center, approximately \$400 to \$600K, discourages their use in this application.

3.3 Modular Systems

Between the component-based system and the machining center is a class of equipment referred to as modular systems. Modular systems offer a high degree of flexibility without the complexity of the component-based system. The modular system has capabilities similar to the machining center, but is not an all-in-one stand-alone unit. The typical modular unit has a spindle mounted to a three axis translation stage. The interfacing and control features are an integral part of the unit. As an option, torque and position sensing can be incorporated into the unit as well as tool change capability. For application to the fuel disassembly task, two or perhaps three modular units would be used. One or possibly two units would be used for drilling, and the third would push the fuel compacts out. The speed and accuracy offered by these machines may alleviate the necessity of drilling both ends simultaneously. Manufacturer specifications show the modular system could index and drill a hole in less than 5 s. Based on this figure, approximately 30 minutes would be required for a single milling unit to expose the holes on both ends. Since a single cutter is drilling all holes, tool wear becomes a question; however, the automatic tool changing capabilities does mitigate this concern. A layout of a modular system is shown in Figure 10.

Figure 10. Modularized system schematic.

3.4 Cutting Tools

Several options were considered regarding cutting tools. These options include single cutters, multihead spindle cutters, coring mills, end mills, and gun drills. Companies are eager to manufacture specific tools designed for specialized applications. Many manufacturers suggested using diamond impregnated cutters to fight abrasion and increase tool life.

Included in Appendix A are several catalog cut outs of available cutters. Virtually any tool design can be procured from a number of companies.

4. CONCLUSIONS

The following conclusions were derived from the tradeoff study:

1. Use of a sensing probe is the preferred verification method of fuel element type and fuel element position.
2. Use of an end mill to cut a single hole is the preferred method of fuel exposure.
3. Use of an integrated cutter and vacuum is the preferred method of graphite dust removal.
4. Use of a pneumatic ram is the preferred method of fuel compact removal and verification of removal

5. DESIGN RECOMMENDATIONS

A recommendation is made to use a system comprised of the preferred methods outlined in the Conclusions Section. This system would contain (1) the drilling station and (2) the fuel removal station. The system would specifically contain the following components:

- A sensing probe (to determine the fuel element type and the relative position of the fuel element with respect to the drilling equipment)
- A drilling machine equipped with diamond impregnated cutter, an automatic tool changer, and a vacuum system (to facilitate graphite dust removal)
- A pneumatic cylinder (to push the fuel compacts out of the graphite fuel element)

A design was formulated that incorporates the most attractive features of the equipment previously considered.

A single modular milling unit is recommended to drill the fuel element faces. With a single spindle cutter, the unit will drill one end-face of the element, the block will be rotated 180 degrees, and the other end-face drilled. Since elevation of the fuel compacts is not predictable, as demonstrated by GA tests, the milling unit must be equipped with a torque sensor to determine when the cutter has broken through the graphite into the fuel hole. Since only one cutter is used to drill both faces, tool wear is a concern. Therefore, a recommendation is that diamond impregnated cutters and a tool changer be an integral part of the unit. Using a sensing probe, the milling center will have the capability of determining the fuel element type as well as its position relative to the drilling and removal equipment.

Another recommendation is that the graphite dust removal system also be an integral part of the milling unit. A suggested method is to equip the unit with a system that would permit pulling a vacuum at the cutting surface through the tool shank.

5.1 System and Operation Description

The recommended design is shown schematically in Figures 11(a) and 11(b). The system is divided into two constituent parts: (1) the drilling station and (2) the fuel removal station.

The drilling station is comprised of a horizontal single-spindle CNC machine with X, Y, and Z positioning equipment as an integral part of the milling unit. The machine has an automatic tool changer that holds several spare cutters and at least two sensing probes. A sensing probe is used to identify the block type and verify block position. The CNC controller is independently programmable as well as computer programmable. In order to track tool wear and determine hole break-through, the controller may be used to monitor cutting torque. The unit has a vacuum system attached to the spindle that permits waste generated during cutting to be drawn through the cutter shank. The work table is attached to the milling unit and supports a 360 degree rotating table. Rotation of the table is controlled by the CNC controller.

Figure 11(a). Conceptual design schematic of fuel disassembly equipment.

Figure 11(b). Section A-A of fuel disassembly equipment conceptual design.

The fuel removal station consists of a push rod operated by a pneumatic cylinder mounted on an X-Y positioning table. The pneumatic cylinder is attached to the positioning table by quick release clamps to aid in remote maintainability of the system. The push rod is activated by plant air, throttled using valves controlled by either the CNC controller or a second control system. A bushing with wire bristles is mounted just behind the blunt end of the rod. The wire brush bushing is used to sweep loose particles out of the fuel hole. Push rod position is monitored and controlled using a position switch attached to the cylinder wall and relays a signal to the controller, and subsequently to the computer. The pneumatic clamping fixture is also operated using this control system.

Positioning of the cylinder relative to the workpiece is accomplished using the vertical and horizontal translation tables driven by servos controlled from the same system as the pneumatic cylinder.

Figure 12 is a diagram of the control operations and interfaces for the disassembly equipment. The possibility of eliminating the second controller and using the CNC controller for all equipment is being investigated. This would reduce the amount of hardware necessary and would also reduce the complexity of the control system. An isometric drawing of the integrated system is shown in Figure 13.

The fuel disassembly equipment is designed for fully automatic operation with manual override capability. A flow chart detailing the disassembly operation is shown in Figure 14.

6. SUMMARY

A Conceptual Design Report (CDR) has been prepared for mechanical disassembly of the FSV fuel elements. The CDR contains the requirements, assumptions, tradeoff study of the various methods that could be used, description of the various components and their operation, and a recommended conceptual design of a preferred system to accomplish the mechanical disassembly of the fuel elements.

Figure 12. Control and interface of fuel disassembly equipment.

Figure 13. Layout of modular fuel disassembly equipment.

Figure 14. Operation flow chart of fuel disassembly equipment.

APPENDIX A. SAMPLING OF AVAILABLE EQUIPMENT

Catalog cut outs of a sample of equipment surveyed were assembled and are presented in this section of the report.

MULTIPLE SPINDLE CUTTING HEADS

Model 500 Multi-Drill

STURDY, COMPACT HEAD WITH HEAVY-DUTY CAPABILITIES

Ideal for adaptation to drill presses, tapping machines, automatic self-feed drill and tap units, and special machines.

- Available with adjustable arm or slip spindle assembly using bored fixed position plate.
- Low profile — compact, close couple design. Minimum amount of open height taken up.
- Allows a more comfortable working position for the operator.
- Heavy-duty gear case allows drilling up to 6 holes, $\frac{3}{8}$ " drill capacity in mild steel, in a $4\frac{3}{4}$ " diameter circle.

- Close center capability.
- Extremely versatile, maximum flexibility of application.
- Operate in any position upright, inverted, or horizontal.
- Adapt to any drilling machine... standard adapter caps available to fit most popular drilling machines.
- These drill heads can be used for multiple tapping by use of a motor reversing unit.
- Heavy-duty universals require minimum maintenance.

Multi Drill Heads (fixed type)

- 3 Spindle Drill Head

- 4 Spindle Drill Head

CUTTING TOOLS

Drilling 1.515" – 3.228" diameter

ABS®-KUB Insert Drills adjustable external cutting edge

ABS®-KUB Insert Drill

Drilling depth $N = 2 \times D$ and $N = 3 \times D$

Adjustable

The external insert pocket can be radially adjusted to the diameter required. See D – adjustment range.

- Any intermediate dimension for drilling up to $D + 0.040/-0.020$ " with adjustable external insert pocket.
- Saving of a machining operation by direct drilling of the correct preset dimension (for precision machining, precision reaming, etc.).
- Designed with same overall dimension as our long established $2 \times D$ and $3 \times D$ ABS KUB insert drills.
- Drilling to size.
- Reduction in tool maintenance costs by replacement of special tools with intermediate dimensions.
- Internal coolant supply directly onto the cutting edges.
- Spiral flutes for removal of chips from cutting area.

- stock standard
- non-stocked standard delivery on request

Drilling depth $N = 2 \times D$					
Order No.	ABS size d	D adjustment range	N	L	(lbs)
○ V82 33901	50	1.515 – 1.574	3.071	5.039	2.426
○ V82 34001		1.555 – 1.614	3.150	5.118	2.426
○ V82 34101		1.594 – 1.653	3.228	5.197	2.536
○ V82 34201		1.633 – 1.692	3.307	5.276	2.646
○ V82 34301		1.673 – 1.732	3.386	5.354	2.756
○ V82 34401		1.712 – 1.771	3.465	5.433	2.756
○ V83 34501	60	1.751 – 1.811	3.543	5.709	3.859
○ V83 34601		1.791 – 1.850	3.622	5.787	3.969
○ V83 34701		1.830 – 1.889	3.701	5.866	4.079
○ V83 34801		1.870 – 1.929	3.780	5.945	4.190
○ V83 34901		1.909 – 1.968	3.858	6.024	4.301
○ V83 35001		1.948 – 2.007	3.937	6.102	4.410
○ V83 35101		1.988 – 2.047	4.016	6.181	4.520
○ V83 35201		2.027 – 2.086	4.094	6.260	4.520
○ V83 35301		2.066 – 2.125	4.173	6.339	4.741
○ V83 35401		2.106 – 2.165	4.252	6.417	4.961
○ V84 35501		2.145 – 2.204	4.331	6.496	6.723
○ V84 35601		2.185 – 2.244	4.409	6.575	6.836
○ V84 35701		2.224 – 2.283	4.488	6.654	6.946
○ V84 35801		2.263 – 2.322	4.567	6.732	7.056
○ V84 35901	80	2.303 – 2.362	4.646	6.811	7.277
○ V84 36001		2.342 – 2.401	4.724	6.890	7.387
○ V84 36101		2.381 – 2.440	4.803	6.969	7.607
○ V84 36201		2.421 – 2.480	4.882	7.047	7.828
○ V84 36301		2.460 – 2.519	4.961	7.126	8.048
○ V84 36401		2.501 – 2.559	5.039	7.205	8.159
○ V84 36501		2.539 – 2.598	5.118	7.283	8.379
○ V84 36601		2.578 – 2.637	5.197	7.362	8.710
○ V84 36701		2.618 – 2.677	5.276	7.441	8.820
○ V84 36801		2.657 – 2.716	5.354	7.913	8.930
○ V84 36901		2.696 – 2.755	5.433	7.992	9.592
○ V84 37001		2.736 – 2.795	5.512	8.071	9.923
○ V84 37101		2.775 – 2.834	5.591	8.150	10.474
○ V84 37201		2.814 – 2.874	5.669	8.228	10.584
○ V84 37301		2.854 – 2.913	5.748	8.307	10.694
○ V84 37401	80	2.893 – 2.952	5.827	8.386	11.246
○ V84 37501		2.933 – 2.992	5.906	8.465	11.466
○ V84 37601		2.972 – 3.031	5.984	8.543	11.576
○ V84 37701		3.011 – 3.070	6.063	8.622	11.797
○ V84 37801		3.051 – 3.110	6.142	8.701	12.348
○ V84 37901		3.090 – 3.149	6.220	8.780	12.458
○ V84 38001		3.129 – 3.188	6.299	8.858	12.679
○ V84 38101		3.169 – 3.228	6.378	8.937	13.010

Caution:

When drilling rotating parts, a slug as shown pops out when drill breaks thru – and can be thrown free from the chuck with tremendous force.

Adequate guards are an absolute necessity.

SELF FEEDER DRILLS

SELF FEEDERS

Rugged, precise, dependable, compact units

● SFA type

The smallest series in the Sugino range. It has a new high efficiency air motor and control system. This series has been specially designed for high speed small diameter drilling. There are two models; SFA 2300 with a maximum speed of 32,000; SFA 3070 with a maximum speed of 7,500 rpm.

● SFB type

This series of Selffeeders is suitable for drill sizes ranging up to 17/64 in. diameter when drilling steel. The various models in this series cover a speed range from 700 rpm to 17,000 rpm.

● SFC type

For drill sizes up to 3/8 in. diameter when drilling steel. The speed range covered by this series is from 300 rpm to 4,300 rpm. # 2000

PNEUMATIC CYLINDERS

ANATOMY OF THE BIMBA DOUBLE-WALL®

MODULAR MILLING UNITS

MODULAR FLEXIBILITY

CNC MACHINING CENTER or
CNC WING UNIT. It's Your Choice

Standard No. 3 JIC Mount for Table Attachment to Base Allows for Multiple Unit Configurations. To Convert from **Stand Alone** or **Cellular** Configuration . . . Just Remove the Table and Convert the Cell Con to a **CNC Wing Unit**.

Duplex Horizontal Milling, Drilling, Tapping and Borematic Configuration.
(Two Machines, Single Table)

Dial Index Configuration when Used as Standard CNC Wing Base.
(Three Machines, No Tables)

Transfer Line Configuration using as Standard CNC Wing Base.
(Three Machines, No Tables)

Manufacturing Cells using Multiple Stand Alone Machines Grouped as a Cell.
(Three Machines with Tables)

MACHINING CENTERS

New MAXIM 500 And 630 Horizontal CNC Machining Centers

A-18

APPENDIX B. EQUIPMENT SPECIFICATIONS

The fuel disassembly equipment will be procured as four separate items (1) drill station, (2) rod eject station positioning tables, (3) pneumatic cylinder, and (4) computer system. This section of the report outlines the specifications for the first three items; the computer system specification is still under development.

B.1 Drill Station Requirements for the Fort St. Vrain Fuel Disassembly System

Specifications and requirements for the drill station and system controller are detailed on the following drawing and note page.

NOTES:

1. THIS DRAWING APPLIES TO EQUIPMENT TO BE USED TO DEMONSTRATE THE REMOTE DRILLING OPERATIONS REQUIRED FOR REMOVAL OF FUEL COMPACTS CONTAINED WITHIN THE HEXAGONAL GRAPHITE FUEL ASSEMBLIES.

10. THE FUEL EJECT STATION :
OF A PNEUMATIC RAM MOUNTED
OF THE PNEUMATIC CYLINDER
PROVIDE POSITIVE VERIFICATION
THE X-Y POSITIONING TABLE

D THE FUEL DISASSEMBLY EQUIPMENT, COMPRISED OF THE DRILLING STATION AND THE ROD EJECT STATION, WILL BE LOCATED WITHIN A HOT CELL AND SHALL BE CAPABLE OF BEING OPERATED REMOTELY FROM OUTSIDE THE HOT CELL VIA COMPUTER INTERFACE. MODULARIZED EQUIPMENT SHALL ALSO INCLUDE ASSOCIATED MOTION CONTROLLERS AND PROGRAMMING/OPERATOR PANELS FOR REMOTE OPERATION AND INTERFACE WITH A PERSONAL COMPUTER.

X-AXIS (LATERAL)
Y-AXIS VERTICAL
POSITIONING ACCURACY
REPEATABILITY AND
RAPID TRAVERSE

3. THE DRILLING STATION SHALL BE CAPABLE OF PROCESSING TWO FUEL ELEMENTS PER EIGHT HOUR SHIFT. RELIABILITY OF EQUIPMENT SHALL BE SUCH THAT THREE THOUSAND (3000) FUEL ELEMENTS MAY BE PROCESSED WITHOUT SIGNIFICANT EQUIPMENT FAILURE.

IN ADDITION TO CONTROLLING
SHALL ALSO BE CAPABLE

DRILL CYCLE:

TWO FACES/FUEL ELEMENT - (210) 0.500 DIA HOLES X 0.50 DEEP/FACE

FUEL ELEMENT MATERIAL - GRAPHITE TYPE H451 OR H322

FUEL ELEMENT SIZE/CONFIGURATION - HEXAGONAL CROSS SECTION (14.172 INCHES ACROSS FLATS) X 31.22 INCHES LONG - WEIGHT APPROX 300 POUNDS.

SIMULTANEOUS (X, Y, Z)
MINIMUM INPUT/OUTPUT
INTERPOLATION - LINEAR AND CIRCULAR
INPUT/OUTPUT INTERFACE - RS232
CHARACTER DISPLAY - 9 INCH MONOCHROME CRT (MINIMUM)
FEED RATE OVER RIDE - 0 TO 150% IN 10% STEPS
RAPID TRAVERSE RATE OVER RIDE - 0%, 25%, 50%, 100%
SPINDLE SPEED OVER RIDE - 50% TO 150% IN 10% STEPS

4. THE DRILLING STATION SHALL BE AN INTEGRAL UNIT COMPRISED OF A DRILL HEAD MOUNTED ON A THREE (3) AXIS POSITIONING TABLE AND A ROTARY TABLE MOUNTED ON A STATIONARY TABLE SECURELY ATTACHED TO THE 3-AXIS POSITIONING TABLE. THE DRILLING STATION SHALL BE PROVIDED WITH IT'S OWN CONTROLLER CAPABLE OF INTERFACE WITH THE SYSTEM PC COMPUTER. THE DRILLING STATION SHALL BE CAPABLE OF:

11. THE X-Y POSITIONING TABLE
RAM AND RELATED EQUIPMENT
ROD FORCES.

X- AXIS (LATERAL MOVEMENT) - 24 INCHES (MINIMUM)

Y- AXIS (VERTICAL MOVEMENT) - 16 INCHES (MINIMUM)

Z- AXIS (LONGITUDINAL MOVEMENT) - 16 INCHES (MINIMUM)

B- AXIS (ROTARY TABLE MOTION) - 360° ROTATION, INDEXABLE TO 0°, 90°, AND 180° POSITIONS.

PNEUMATIC RAM MOUNTED
WEIGHT -
LENGTH -
MFG. MODEL NO.
MAX APPLIED FORCE

RPM- SPINDLE SPEED - CONTROLLABLE FROM 0 TO 2000 RPM

SPINDLE MOTOR MAX RATING - 15 HP (11.5 KW)

CUTTING FEED - 0 TO 20 INCHES PER MINUTE

POSITIONING ACCURACY - ± 0.0002 INCHES

REPEATABILITY - ± 0.0001 INCHES

SPINDLE NOSE - NT NO. 45

RAPID TRAVERSE (ALL AXIS) - 787 IPM

TOOL MAGAZINE CAPACITY - 6 TOOLS MINIMUM

FEED INCREMENTS - .01 IPM

5. IN ADDITION TO CONTROLLING FUNCTIONS NOTED THE DRILL STATION CONTROLLER SHALL ALSO BE DRILL STATION CAPABLE OF:

SIMULTANEOUS CONTROL OF THE X, Y, AND Z AXIS

MINIMUM INPUT/OUTPUT RESOLUTION - 0.0001 INCHES

INTERPOLATION - LINEAR AND CIRCULAR

INPUT/OUTPUT INTERFACE - RS232

CHARACTER DISPLAY - 9 INCH MONOCHROME CRT (MINIMUM)

FEED RATE OVER RIDE - 0 TO 150% IN 10% STEPS

RAPID TRAVERSE RATE OVER RIDE - 0%, 25%, 50%, 100%

SPINDLE SPEED OVER RIDE - 50% TO 150% IN 10% STEPS

6. THE DRILLING STATION SHALL BE EQUIPPED WITH AUTOMATIC TOOL CHANGE CAPABILITY WITH MINIMUM OF SIX TOOLS. THE TOOL-TO-TOOL CHANGE OUT TIME SHALL BE LESS THAN 30 SECONDS.

7. THE DRILL STATION SHALL BE EQUIPPED WITH A DEVICE CAPABLE OF SENSING DRILL BREAKTHROUGH AND STOPPING FORWARD MOTION OF THE SPINDLE WITH IN 0.005 INCHES OF DRILL PENETRATION (Z-AXIS MOTION).

8. VACUUM CAPABILITY SHALL BE PROVIDED THROUGH THE DRILL SPINDLE FOR REMOVAL OF GRAPHITE DUST AND CHIPS. THE VACUUM SYSTEM SHALL BE CAPABLE OF DRAW DOWN TO TBD IN H_2O .

9. A SENSING PROBE SHALL BE PROVIDED WITH THE EQUIPMENT AND SHALL BE CAPABLE OF SENSING THE WORK PIECE FEATURES WITH THE X, Y, AND Z POSITIONING ACCURACY OF ± 0.0002 INCHES.

[illegible]

PLAN

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B.2 X-Y Positioning Table Requirements for the Fort St. Vrain Fuel Disassembly System

An X-Y motorized positioning table of the configuration shown on the following sketch is needed for the Fort St. Vrain Fuel Disassembly System. The positioning table serves to index and support a pneumatic cylinder at the fuel hole locations in a fuel assembly. The cylinder is then actuated to push the fuel out of the assembly. Requirements for the positioning table are:

1. Horizontal travel (X-axis)	-minimum of 18 inches
2. Vertical travel (Y- axis)	-minimum of 18 inches
3. Travel speeds (both axes)	-minimum of 750 inches per minute
4. Table width	-minimum of 12 inches
5. Loads	
cylinder weight	-approximately 40 pounds
cylinder pushing force	-150 pounds
6. Operating environment	-75 degrees Fahrenheit
-abrasive carbon dust
-beta and gamma radiation
7. Materials must be resistant to gamma radiation, for example	
radiation hardened motors	-possible source, Empire Magnetics
lubricants	-recommendation, Dow Corning #44 grease
elastomers	-recommendation, ethylene propylene rubber
8. Positioning requirements	
closed loop control	-compatible with a GE FANUC-6M controller
position accuracy	-less than 0.002 inches/foot
position repeatability	-less than 0.002 inch
sensors	-end of travel/home sensors
9. Life	-600,000 total inches of travel for each axis

A controller is required for controlling the positioning table and the pneumatic cylinder (see Schematic of the Fuel Eject Station). It is preferable that the controller for the table and the cylinder be the same one used for controlling the drill station. In addition to meeting the indexing requirements specified for the positioning table, the controller also has the following requirements:

- Simultaneous control of the X-Y axis of the positioning table
- Interface with a personal computer via RS 232 input/outputs
- Minimum input/output resolution - 0.0001 inches
- Interpolate - linear and circular
- Character display - 9 inch monochrome CRT
- Rapid table traverse over-ride 0%, 25%, 50%, 100%
- Toggle the cylinder air supply off and on
- Toggle the cylinder direction based on cylinder stroke position signals
- Toggle the cylinder over-ride pressure supply on and off based on a rod force signal

B.3 Pneumatic Cylinder for Fort St. Vrain Fuel Disassembly System

A pneumatic cylinder is needed for the Fort St. Vrain Fuel Disassembly System. The function of the cylinder, as illustrated on the following page, is to push the uranium fuel out of the fuel assembly. The cylinder is indexed and held in position by an X-Y positioning table. Requirements for the pneumatic cylinder are:

1. 1-3/4 inch diameter bore
2. 36 inch stroke
3. double acting
4. 7/16 inch diameter, stainless steel rod
5. rod end must have 1/4-20 UNC female thread a minimum of 5/8 inch deep
6. adjustable cushions at both ends of the cylinder
7. magnetic piston for activating external magnetic reed switches
8. cylinder may be either aluminum or stainless steel
9. all elastomer seals are to be ethylene propylene rubber
10. rod guide bushing shall be graphite (possible source Pure Carbon Co.)
11. cylinder must to be permanently lubricated with Dow Corning's #44 medium weight grease or a lubricant with similar radiation resistance

DATE

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END