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DESIGN EVALUATION OF THE HTGR FUEL ELEMENT SIZE REDUCTION SYSTEM

by
J. B. STRAND

**Prepared under
Contract EY-76-C-03-0167
Project Agreement No. 53
for the San Francisco Operations Office
Department of Energy**

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GENERAL ATOMIC COMPANY

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ABSTRACT

A fuel element size reduction system for the "cold" pilot plant of the General Atomic HTGR Reference Recycle Facility has been designed and tested. This report is both an evaluation of the design based on results of initial tests and a description of those designs which require completion or modification for hot cell use.

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1. INTRODUCTION

At the direction of the Department of Energy (DOE), General Atomic Company has been given the responsibility for development and testing of equipment and processes for a "cold" pilot-scale plant for an HTGR Reference Recycle Facility (HRRF). A part of this responsibility is the development of a fuel element size reduction system.

The entire pilot plant process consists of crushing of fuel elements to a size suitable for burning in a fluidized bed to remove excess graphite; separation, crushing, and reburning of fissile and fertile particles to remove the majority of the remaining graphite; dissolution and separation of the particles from insoluble materials; and solvent extraction separation of the uranium and thorium.

The fuel element crushing process is accomplished via a three-stage crushing system consisting of two overhead eccentric jaw crushers, a double-roll crusher, and an oversize monitoring system (screener, flow rate sensor, and oversize crusher) to ensure reduction to a size suitable for fluidized bed burning.

The major equipment for the crushing system is mounted in a specially designed framework that replaces the standard machine frame of the overhead eccentric jaw crushers and the roll crusher in an array which utilizes gravity flow, eliminates the requirement for material transport devices, and minimizes material holdup. The entire system has been designated UNIFRAME because of the integration of all the equipment into this specially designed structure. The completely assembled UNIFRAME is shown in Figs. 1 and 2.

This report presents an evaluation of the initial design of the UNIFRAME fuel element size reduction system and its components.

16					
15					
14					
13					
12	26	5210002-15	STD WASHER	STEEL	COM L
11	26	12	1/8 NC HEX NUT		
10	32	11	1/8 NC HEX NUT		
9	16	10	1/8 NC + 11 MACH BOLT	STEEL	COM L
8	4	9	3/16 KEY 1/2 x 3/8	STD	
7	2	8	3/16 KEY 1/2 x 3/8	STD	
6	1	7	3/16 KEY 1/2 x 3/8	STD	
5	1	6	5210032-6	CC 1/2 INCH DIA HOLE WITH 1/8 INCH DIA HOLE	
4	1	5	5210032-4	PLASTIC 1/2 INCH DIA HOLE WITH 1/8 INCH DIA HOLE	
3	1	4	5210032-1	TEST AGY BOLL COVE SPOCKET	
2	1	3	5210031-1	CO 1/2 PLASTIC FOOTING CO. SHEET	
1	1	2	5210019-1	MECHANICAL SUB SYSTEM IN REPAIR	
	1	1	5210002-1	ASSEMBLY	

Fig. 1. Fuel element size reduction equipment assembly

1-8 UNC THRU ITEM 8 & PLACES LOCATE FROM ITEM 3

27	5210008-1	UNIFRAME, MECHANICAL		
1 26	5210015-25	SPACER, 1/8 THK	STEEL	
2 25	5210015-25	SPACER, 1/8 THK	STEEL	
4 24	5210015-25	NUT, JAM, 1-12 UNC	STEEL	
4 23	5210015-25	HEX BOLT, 1-12 UNC	STEEL	
1 22	5210021-1	ENTER CAP, ASSY		
1 21	5210021-1	ENTER CAP, ASSY		
2 20	5210021-1	ENTER CAP, ASSY		
2 19	5210021-1	ENTER CAP, ASSY		
2 18	5210021-1	ENTER CAP, ASSY		
2 17	5210021-1	ENTER CAP, ASSY		
2 16	5210021-1	ENTER CAP, ASSY		
2 15	5210021-1	ENTER CAP, ASSY		
2 14	5210021-1	ENTER CAP, ASSY		
2 13	5210021-1	ENTER CAP, ASSY		
2 12	5210021-1	ENTER CAP, ASSY		
2 11	5210021-1	ENTER CAP, ASSY		
2 10	5210021-1	ENTER CAP, ASSY		
2 9	5210021-1	ENTER CAP, ASSY		
2 8	5210021-1	ENTER CAP, ASSY		
2 7	5210021-1	ENTER CAP, ASSY		
2 6	5210021-1	ENTER CAP, ASSY		
2 5	5210021-1	ENTER CAP, ASSY		
2 4	5210021-1	ENTER CAP, ASSY		
2 3	5210021-1	ENTER CAP, ASSY		
2 2	5210021-1	ENTER CAP, ASSY		
2 1	5210021-1	ENTER CAP, ASSY		

Fig. 2. UNIFRAME mechanical subsystem

2. DESIGN EVALUATION

Throughout the initial testing of the fuel element size reduction system, informal and formal discussions were held with cognizant operating, design, and management personnel regarding problems and failures that occurred and designs that required changes. The purpose of these discussions was to produce a final viable design applicable to a commercial reprocessing facility in a hot cell environment.

The design changes generally agreed upon were categorized for final study as follows: (1) designs requiring modification for hot cell use, (2) designs requiring completion for hot cell use, and (3) designs requiring evaluation. Those designs which require modification for hot cell use are basically acceptable designs that need minor changes to be compatible with remote operation or more severe commercial use but do not require changes that affect their basic function. Those designs which require completion for hot cell use are those which were omitted initially due to programmatic constraints or presented potential problem areas in a hot cell but were judged of low enough priority for testing with low-level radioactive materials as designed. Those designs which require evaluation are those which present a departure from the initial designs or design philosophy and are not obvious needs or viable tradeoffs without further study.

At the completion of initial testing, the designs identified for the above three categories were discussed with cognizant operating, design, and management personnel to determine the design requirements and alternatives and also the advantages and disadvantages of each alternative and of the original designs.

The purpose of this evaluation is not to present designs but rather to identify further design requirements and tests necessary as a basis for sound design decisions.

3. DESIGNS REQUIRING MODIFICATION FOR HOT CELL USE

The following components of the fuel element size reduction system require modification for hot cell use. These designs have been proven basically acceptable in the performance of their intended functions but require minor changes to be compatible with remote operation for long-term commercial use.

3.1. VENTILATION ENCLOSURE

In all of the tests conducted thus far, the ventilation enclosure design has been found to be quite adequate with respect to dust containment and minimization of dust holdup areas. The current design utilizes standard methods and fasteners for attaching the removable panels. Prior to commission for the commercial hot cell reprocessing facility, these attachment methods and fasteners for the removable panels will need modification to be compatible with remote operation and removal. In addition, some modifications which include the ventilation enclosure panels as integral parts of the machine frame may be desirable.

3.2. CRUSHING WEAR SURFACES

The wear surfaces of both the primary and secondary crusher were fabricated of mild steel because of cost considerations and fabricability and to potentially provide wear data. The designs of these surfaces have been proven adequate or have been modified sufficiently so that they perform their process functions as required. For the long-term and more severe use of a commercial reprocessing facility, it will be necessary to merely replace the mild steel surfaces with hardened materials to improve the wear life.

4. DESIGNS REQUIRING COMPLETION FOR HOT CELL USE

The following components of the fuel element size reduction system require completion prior to hot cell use. Although identified as necessary, some of these designs were not completed initially due to budgetary or scheduling constraints. Some of these designs requiring completion are the result of additional needs identified from test observations.

4.1. THROUGH-THE-CELL-WALL DRIVE SYSTEM

The present drive system in the cold pilot plant is defined as the drives necessary for powering the three size reduction stages, the screener, and the oversize crusher. The primary, secondary, and tertiary crusher drives are mounted on a common structure separate from the UNIFRAME structure. Power is supplied individually to each crusher by electric motors connected by V-belts to the primary and secondary crushers and each of the rolls of the tertiary crusher. The screener is driven by a motion generator which is centrally located within the screener housing and is composed of an electric motor with weights eccentrically mounted on each end of its shafts. The oversize crusher is driven by the standard system supplied with the unit, which is composed of an electric motor mounted on a common frame with the other components and connected by V-belts to the eccentric roll.

It was recognized at the onset of the design that a more sophisticated drive system is required for the final UNIFRAME design. The present system was used because budgetary and scheduling considerations precluded the design, purchasing, construction, and testing of the more sophisticated system under those constraints and the facility concept was not adequately defined to allow a firm design selection. The present system has been found to be more than adequate for cold pilot plant tests

of the UNIFRAME components. However, radiation effects on motors, V-belts, and lubricants for bearings and gears and remote maintenance, replacement, and tooling make it desirable to locate as many of the drive system components outside the hot cell as is practical. This necessitates the design and testing of a through-the-cell-wall drive system prior to commission to hot cell use. Completion of the conceptual design has been scheduled for fiscal year 1978.

Requirements of this design will be: reduction of remote maintenance, replacement, and tooling requirements; provision for alignment, realignment, and correction of misalignment during installation, replacement, or repair; avoidance of failures of the drive components, cell structure, and other UNIFRAME components due to shock, vibration, and loading; and the utilization of standard readily available commercial components wherever possible.

4.2. START-UNDER-LOAD CAPABILITY

The design criteria for the UNIFRAME included the requirement that each of the components be capable of starting under loaded conditions. This ability eliminates the potential need to remove uncrushed or partially crushed materials from the system components in the event of shutdown due to power loss, human error, or other reasons and inadvertent charging of materials prior to equipment startup.

Start-under-load capabilities were not specifically addressed for the present drive system because it was recognized that the more sophisticated drive system required for hot cell use would present different start-under-load conditions. The budgetary and scheduling considerations which precluded the more sophisticated drive system also applied to completing start-under-load capabilities.

During the tests completed to date several occasions arose which provided opportunities to observe the start-under-load capabilities of the

present equipment. All equipment, except the primary crusher, readily started under loaded conditions. At this time, it appears that other than the primary stage drive system, no special designs will be required to provide start-under-load capabilities. Completion of the conceptual design for start-under-load capability of the primary crusher is scheduled for fiscal year 1978.

4.3. FUEL LOADING PORT

For cold pilot plant purposes the method for charging the fuel elements to the UNIFRAME was designed to be compatible with available cranes and fuel lift fixtures, existing ventilation capabilities, charging elements singly, and containment practices for low-level radioactive materials.

For the commercial reprocessing facility, the fuel charging system design requirements will include: provision for storage of several fuel elements; automatic conveying; single-element charging through an air lock which is compatible with ventilation requirements; handling and charging capabilities for broken fuel elements; interlocks to prevent double chargings; and remote repair capabilities.

4.4. LUBRICATION SYSTEMS

The present lubrication system in the cold pilot plant is defined as the bearings and lubricants necessary for the proper operation of the major equipment items of the UNIFRAME.

The eccentric shafts of the primary and secondary crushers are oil lubricated by the standard commercial crusher system, which consists of a central galley and wiper system for lubricating the pitman bushings and separate galley and wiper systems for each of the outboard bushings. The toggle-pin joint connections are lubricated by a dry film coating on each of the shafts. The tertiary double-roll crusher and the oversize crusher

have been installed with the manufacturer's standard grease-lubricated roller bearings. The only lubrication required in the screener is on the drive motor for the motion generator which is supplied with its standard sealed roller bearings.

A recirculating oil system or solid graphite bearings have been proposed as alternatives for lubricating the eccentric shafts on the primary and secondary crushers. Components for these alternatives have been received but testing is incomplete.

The present lubrication techniques contain components which can suffer damage from radiation and the consequences of failure are catastrophic, as with roller bearings. More reliable and maintainable lubrication techniques are required for a commercial reprocessing facility. Requirements for the final lubrication system designs include: provisions for remotely replenishing and replacing lubricants, avoidance of catastrophic failures, elimination of potential lubricant leakage, use of radiation-resistant lubricants and component parts, and the reduction of remote maintenance, replacement, and tooling requirements.

4.5. INTERCHANGEABILITY OF PITMAN PARTS

The present designs of the primary and secondary pitmans contain many components such as toggle assemblies and lubrication system parts which are interchangeable between crushers. However, because of the differences in the configuration of the crushing surfaces, plus the added feature of removeability of these surfaces, the machining on the pitman castings renders them quite different. For a commercial facility the need for separate replacement parts of this magnitude in size and cost becomes undesirable. Therefore, for the final design, efforts will be undertaken to design pitman assemblies which are interchangeable with the exception of the removable crushing surfaces which necessarily must be different.

4.6. SECONDARY CRUSHER CLEARING DEVICE

On several occasions during the initial testing of the secondary crusher, materials failed to crush completely. Further investigation of the problem demonstrated that it was related mainly to the angle between the pitman and stationary jaw crushing surfaces (nip angle). Angles which were too large allowed the material to slip upward in the crushing cavities, thus avoiding crushing. A series of tests established that at angles of 14.5° or less unirradiated graphites crushed readily. By machining the crushing surface on the pitman, the 14.5° angle was extended as far up the curved wear surface as was practical. In succeeding tests, crushing failure occurred only once in 62 experiments; this material was crushed readily after its location in the crushing cavity was altered by external means. Even at this low frequency of occurrence, it is necessary to provide a means for clearing uncrushed materials in the secondary crusher. Even though heldup material may self-clear due to movement and pressures from subsequent chargings or wear and movement caused by the crushing action of the moving pitman, the heldup material could cause blockage of subsequent material holdup, ultimately resulting in the need to dismantle equipment to clear the cavity.

The requirements for the clearing device in a final design include simplicity of operation; minimization of remote maintenance and tooling requirements; and no effect on normal crushing operations.

4.7. OVERSIZE CRUSHER

The preceding tests on the oversize crusher revealed that it did not reduce all of the oversize material to $\leq 4780 \mu\text{m}$ as required. This was attributed to the spring loading of the wear plates, which allows them to be pushed away from the roll by the flow of material between the plates and the eccentric roll, effectively increasing the gap. These gaps are difficult to set properly even under cold pilot plant conditions and would

be even more difficult to set under remote conditions. In addition, the crusher design allows material holdup in the cavities behind the wear plates. These factors make it necessary to upgrade the present oversize crusher design and investigate viable alternative designs such as double-roll crushers.

5. DESIGNS REQUIRING EVALUATION

The following designs of the fuel element size reduction system are evaluated with respect to alternatives. These designs were identified as having viable alternatives with sufficient merit to warrant consideration.

5.1. PRIMARY CRUSHER CLEARING DEVICE

5.1.1. Introduction

Occasionally during testing of the UNIFRAME system, fragments of fuel elements would fail to crush in the secondary crusher. By extending the 14.5° nip angle as far up the face of the curved wear plate as practical, the frequency of this occurrence was reduced to once in 38 tests with loaded and unloaded fuel elements plus 24 tests with scrap anode butt graphite. This single occurrence necessitated the requirement for a clearing device in the secondary crusher to avoid the potential dismantling of equipment to remove the material thus held up. It also made it desirable to investigate the need for a clearing device in the primary crusher.

5.1.2. Function of Primary Crusher Clearing Device

The primary function of the primary crusher material clearing device is to provide a method for completion of crushing of material which has failed to crush completely and is therefore held up in the crushing cavity.

5.1.3. Design Criteria for Primary Crusher Clearing Device

Any clearing device designed for the primary crusher would be added with the avoidance of crushed material holdup as the primary criterion, as well as meeting the performance requirements for the size reduction system and the primary crusher.

5.1.4. Operating Experience

Failure of materials to crush completely occurred several times in the initial individual tests of both the primary and secondary crushers. Investigation of the problem showed it to be related mainly to nip angles which were too large and allowed the material to slip upward instead of crushing. The nip angles were changed, and no further failures to crush were observed in the primary crusher. However, a single failure in the 62 succeeding tests did occur in the secondary crusher.

5.1.5. Advantages and Disadvantages of Clearing Device for Primary Crusher

The advantages of the clearing device are:

1. Provides a means of clearing material held up in the crushing cavity without dismantling equipment.
2. Decreases the desirability of a variable nip angle in the primary crusher merely to avoid the potential of rare failures to crush the material completely.

The disadvantages of a clearing device are:

1. Requires additional component parts that can fail.
2. Increases the complexity of the design.
3. May require additional special and complex remote operating devices and tools.
4. May require penetrations through the ventilation enclosure or removable panels which add to its complexity and increase the probability of dust escaping.

5. Provides no assurance that holdup cannot occur which the device is unable to clear.
6. May require the provision of side and/or height clearances in the cell for operation.

5.1.6. Discussion

There are several factors which reduce the necessity of a clearing device in the primary crusher. Material holdup in the primary crusher has not been experienced in any of the tests at nip angles of 14.5° or less and it is not now known that holdup will occur. Smaller nip angles will increase the probability of crushing and will be incorporated in the final design as fixed angles or as adjustment capabilities. Holdup from one element has a possibility of clearing due to movement of the fragments or additional loads from the crushing of a subsequent element. For events such as shutdowns prior to completion of crushing, start under load is a design requirement separate from the need for a clearing device. This type of clearing may be possible by reversing the drive on the crusher.

Material holdup is a serious consideration from the standpoint of safeguards and accountability as well as operational requirements. However, no clearing device can guarantee that a form of holdup which the device is unable to clear will not occur, no matter how unlikely, and thus dismantling of the equipment would still be required.

5.1.7. Recommendations

5.1.7.1. Design Efforts

Design of a clearing device or technique with simplicity and ease of remote operation as criteria should be completed, along with a study of techniques and operations for clearing holdup without the device.

5.1.7.2. Decision Basis

The decision to exclude or include the clearing device in the final commercial hot cell system should be based on considerations of (1) the achievable nip angle in the final design, (2) the simplicity of the clearing device and its failure modes and effects, (3) the start-under-load capabilities including reversability of the drive, and (4) the incidence of holdup which occurs in the remaining crusher tests.

5.2. VARIABLE PRIMARY CRUSHER NIP ANGLE

5.2.1. Introduction

The primary crusher stationary jaw can be adjusted to change the included angle (nip angle) between it and the movable jaw (pitman). This assembly is shown in Fig. 3. Detailed drawings are included in the Appendix.

The primary crusher nip angle is adjusted by loosening the bolts that secure the shafts to anchor blocks welded to the machine frame, loosening the locking devices on the adjustment bolts, and turning the adjustment bolts inward or outward until the desired angle is achieved. The inward travel of the adjustment bolts is limited by the clearance between the stationary jaw cheek plates and the pitman face and by the minimum gap which will allow a fuel element to enter the crusher. The outward travel of the adjustment bolt is limited to the maximum allowed by the clearance between the back of the jaw and the adjustment assembly. After the angle has been confirmed by measurement and the shaft securing bolts and the locking devices on the adjustment bolts have been tightened, the crusher is ready to resume normal operation.

This feature of the stationary jaw was considered desirable because the exact nip angles required to crush unirradiated and irradiated fuel elements could not be established for the primary crusher prior to actual

Fig. 3. Illustration of the basic components of primary crusher nip angle adjustment

tests. Since then, tests have more clearly identified the nip angle required for crushing unirradiated graphite. Because of the potential benefits of a fixed stationary jaw (described in Section 5.3) and a demonstrated desirability of the smallest nip angle practicable, it became desirable to also investigate the potentials of a fixed nip angle.

5.2.2. Function of Variable Nip Angle on Primary Crusher

The primary function of the variable nip angle is to allow adjustments on the primary crusher which could compensate for potential differences in crushing behavior between irradiated and unirradiated fuel elements.

5.2.3. Design Criteria for Primary Crusher Nip Angle

The main criterion for the primary crusher nip angle is to ensure crushing of whole, partial, broken, and damaged fuel and control rod elements without holdup.

5.2.4. Operating Experience

As previously described (Section 5.1.4), failure of materials to crush occurred in the initial individual tests of both the primary and secondary crushers. Further investigation of the problem showed it to be related mainly to nip angles which were too large and thus allowed the material to slip upward in the crushing cavities instead of crushing to completion. A series of tests established that at nip angles of 14.5° or less, unirradiated fuel element graphites crushed readily. A 14° nip angle on the primary crusher was selected for use in all of the succeeding tests to further increase the probability of crushing to completion. No failures to crush and no holdup were experienced in primary crushing or system tests completed using the 14° nip angle.

5.2.5. Advantages and Disadvantages of a Fixed Nip Angle on the Primary Crusher

The fixed nip angle has the following advantages:

1. Reduces the number of component parts required.
2. Does not require additional remote devices.
3. Decreases the complexity of the stationary jaw design.
4. Does not require additional penetrations in the ventilation enclosure.
5. Does not impose additional restrictions on the machine frame design.
6. Does not require additional cell clearance.
7. Allows for ease in inclusion of fixed jaw design in system.

The fixed nip angle has the following disadvantages:

1. May decrease the probability of crushing to completion without material holdup.
2. Does not allow opening crushing cavity to remove heldup material and may increase the desirability of a material clearing device.

5.2.6. Discussion

At any particular close side setting, the minimum fixed or variable nip angle on the primary crusher is limited to that which provides an opening (gap) between the movable and stationary jaws at the top of the

crusher which allows a full-sized fuel element to enter sufficiently to be crushed. The gap can be expanded by extending the length of the jaws, but this imposes additional height requirements on the facility. The previous tests have shown that reducing the nip angle increases the probability of crushing the fuel element completely without material holdup. Therefore, any prudent design of either a fixed or variable nip angle will include the minimum nip angle practicable within the design constraints.

5.2.7. Recommendations

5.2.7.1. Design Efforts

The design of a primary crusher with the smallest practicable fixed nip angle should be completed for inclusion in the commercial hot cell system.

5.2.7.2. Decision Basis

Since the minimum nip angle practicable maximizes the probability of crushing to completion without material holdup over any larger angle, there are no overshadowing reasons to allow for the larger angles provided by the variable nip angle design. The added complexity of the variable nip angle design, its requirements for additional remote tools, the increased complexity and penetrations in the ventilation enclosure, and the restrictions imposed on the machine frame make it less desirable than a fixed nip angle.

5.3. REMOVABLE STATIONARY JAW, PRIMARY AND SECONDARY CRUSHERS

5.3.1. Introduction

Both the primary and secondary crushers have stationary jaws which are designed to be removable and reversible. The primary crusher stationary jaw can also be adjusted to change the included angle (nip

angle) between it and the movable jaw (pitman). These assemblies are shown in Figs. 4 through 6. Detailed drawings are included in the Appendix.

The primary crusher stationary jaw is removed by the following general procedure:

1. Necessary sections of the ventilation enclosure are removed.
2. A remote lift fixture is attached to the top of the stationary jaw.
3. The nip angle adjustment assemblies are removed to provide clearance.
4. The bolts which secure the shafts to anchor blocks welded to the machine frame are loosened.
5. The entire assembly is lifted clear of the machine frame using the remote lift fixture.

If the stationary jaw has not mechanically failed but one side is unuseable because of excessive wear on the crushing surfaces, it can be reversed by removing and replacing the cheek plates on the opposite face of the jaw.

As previously described (Section 5.2.1), the nip angle is adjusted by loosening the bolts that secure the shafts and turning the adjustment bolts until the desired angle is achieved. The angle is limited by the clearance between the cheek plates and the pitman face and the clearance between the stationary jaw and its adjustment assembly. After the angle has been confirmed by measurement and the shaft bolts have been retightened, the unit is ready to resume operations. No dismantling of the ventilation enclosure is required for nip angle adjustment.

Fig. 4. Illustration of basic components of removable and reversible primary crusher stationary jaw

Fig. 5. Illustration of basic components of removable and reversible secondary crusher stationary jaw

Fig. 6. Secondary crusher stationary jaw machine frame attachment

The secondary crusher stationary jaw is removed by the following general procedure:

1. Necessary sections of the ventilation enclosure are removed.
2. A remote lift fixture is attached to the stationary jaw.
3. The upper shaft assemblies are drawn inward. (At this point, the jaw can be laid flat if required.)
4. The lower shaft assemblies are removed.
5. The entire assembly is withdrawn from the machine frame using the remote lift fixture.

As with the primary crusher stationary jaw, if the secondary crusher stationary jaw has not mechanically failed but one side is unuseable because of excessive wear on the crushing surfaces, it can be reversed.

These features of the stationary jaws are considered desirable under the assumption that wear and other failures would require periodic removal. However, since the wear rates have not yet been established and these assemblies are complex and require sophisticated remote fixtures, it also becomes desirable to investigate the potentials for fixed stationary jaws.

5.3.2. Function of Stationary Jaw

The primary function of the primary and secondary crusher stationary jaws is to provide a solid crushing surface which is located at the proper angle and distance from the pitman crushing surface to ensure complete and sufficient material size reduction for the succeeding crushing stage to perform its operation.

5.3.3. Design Criteria for Stationary Jaws, Primary and Secondary Crushers

In addition to meeting the general performance requirements of the size reduction system, the primary and secondary crusher stationary jaws were to be designed to:

1. Contain the fuel element materials so that bypass of crushing was avoided.
2. Utilize gravity for the flow of crushed materials.
3. Avoid holdup of crushed materials, including dusts.
4. Maintain visibility and accessibility to all components.
5. Minimize maintenance requirements.
6. Facilitate remote maintenance.
7. Minimize the requirement for special remote handling fixtures and remote maintenance tools.
8. Use standard interchangeable commercial or designed parts whenever practical.
9. Minimize potential damage to other equipment from failures.
10. Since the jaws are removable, demonstrate remote removal and replacement as assemblies.

5.3.4. Operating Experience

The primary and secondary crushers were individually tested using unfueled HTGR graphite fuel and control rod elements and tested with the UNIFRAME as a system using both fueled and unfueled HTGR fuel and control rod elements and scrap anode butt graphite. Throughout all of these tests, no mechanical failures occurred to either stationary jaw, their removal components or the primary crusher nip angle adjustment assembly. No obvious bypass of the crusher by crushed materials due to the stationary jaw design was observed. No material holdup occurred on the primary crusher stationary jaw, but a small quantity of crushed graphite did lodge in the gaps between the secondary crusher stationary jaw and the side plates. It was suspected that this lodged material could cause problems with the remote removal of the jaw by blocking the necessary clearance between the jaw and side plates. The secondary crusher stationary jaws remote removal fixture has not been completed. Therefore, a test of this feature and its associated equipment and investigation of potential problems has not yet been accomplished. The primary crusher stationary jaw has been removed and replaced using its remote removal fixture. However, this was considered only a preliminary test; thorough tests of the removability of both jaws under remote conditions are required to provide confidence in these design aspects.

5.3.5. Advantages and Disadvantages of Fixed Jaws

The advantages of the fixed jaw are:

1. Reduces the number of component parts required.
2. Does not require additional, special, and complex remote removal devices and tools.
3. Minimizes potential material holdup areas.

4. Decreases the complexity of the stationary jaw designs.
5. Does not require additional penetrations in the ventilation enclosure.
6. Reduces the complexity of the ventilation enclosure.
7. Allows for additional strengthening of the machine frame and for the jaws potentially becoming load-bearing components of the frame.
8. Allows for the jaws to potentially become a part of the ventilation enclosure.
9. Does not require additional side and height cell clearance.

The disadvantages of the fixed jaw are:

1. Potentially requires removal of the entire system for repair of failures or wear out.
2. Renders inclusion of an adjustable nip angle on the primary crusher more difficult.
3. Decreases accessibility to other system components.
4. Renders inclusion of reversibility to minimize the disposal of contaminated parts more difficult.

5.3.6. Discussion

5.3.6.1. Wear

Tests to date with unirradiated graphites have not been extensive enough to reveal wear on either the primary or the secondary stationary

jaw, even though both are presently constructed of mild steel. These mild steel wear surfaces would normally be replaced by hardened materials to improve the life for the more severe commercial use. Since the wear rates from crushing either unirradiated or irradiated fuels have not yet been established, the inclusion of removability and reversibility in the design of the stationary jaws was a precaution against potential wear and not an established need. For a commercial operation, gross wear could be measured in the hot cell during scheduled shutdowns. If sufficient wear occurred to affect the close side settings, it could potentially be compensated for by shims on the pitman providing the strength of the assemblies was not affected.

5.3.6.2. Failures

Assuming that the safety factors for failures due to stress can be established and incorporated in the design of either fixed or removable jaws, the causes of failures other than stress or wear would be related to the number of component parts which could fail. The number of component parts would necessarily be greater for the removable jaw designs than for the fixed jaw designs.

It is possible that failures could occur which would render it impossible to repair the removable jaws or their component parts with the remote tools readily available, necessitating removal of the entire UNIFRAME to effect repair or replacement. The fixed jaw designs with no removable components would probably require removal of the entire UNIFRAME to effect any type of repair.

The additional penetrations and removable panels required in the ventilation enclosure by the removable jaw designs increase the probability of failures to this system and require that remote tooling be available for panel removal. The potential inclusion of one or both stationary jaws as an integral part of the ventilation enclosure in the fixed jaw designs can serve to reduce the probability of these ventilation system failures.

Accessibility to the other components of the UNIFRAME would probably be greater with the removable jaw designs. However, this does not rule out the possibility that the necessary accessibility could be achieved with fixed jaw designs and even enhanced by their simplicity.

5.3.6.3. Remote Fixtures

Presently the designs for remote removal fixtures and tools are not complete. These additional fixtures and tools required for both removal and reversing of the stationary jaws and removal of ventilation enclosure panels for access will be subject to failure also and require tooling for repairs. These failures could render them unavailable for use at the required times.

The additional cell height and floor space requirements for remote removal and the remote tool and replacement parts storage area requirements cannot be determined until all designs are complete. However, these requirements would be greater for the removable jaw design, thus affecting overall plant costs.

5.3.7. Recommendations

5.3.7.1. Wear Tests

Due to the limited availability of unirradiated and irradiated fuels for testing, the wear which would occur under normal tests may be difficult to determine accurately or not sufficient for meaningful design decisions. Therefore, wear tests should be performed using special test equipment which accelerates the time frame and simulates as many of the environmental conditions as practical.

5.3.7.2. Nip Angle Tests

The maximum effective nip angle for crushing irradiated fuels should be determined in hot cell tests which can be related back to the preceding

tests on unirradiated fuels. This would allow meaningful design decisions to be made regarding the secondary crusher nip angle, which is not adjustable in the present design, and regarding the primary crusher nip angle as to whether it remains adjustable or is, as is desired, fixed. Because the probability of crushing increases as the nip angle decreases, any primary crusher design should allow the minimum nip angle possible within practical restraints of height and depth of fuel element entry into the crushing cavity.

5.3.7.3. Design Efforts

Designs of fixed stationary jaws with hardened wear surfaces and the smallest practical nip angles for both the primary and secondary crushers should be completed concurrently with simplified designs which omit the nip angle adjustment on the primary crusher and reversibility on both but include the ability to remove the wear surfaces (semi-fixed design). Completion of these designs will allow a more detailed comparison of their advantages and disadvantages with the removable-reversible designs presently in use, as well as an in-depth study of the potential failure areas.

5.3.7.4. Decision Basis

The decision of which design will be included in the final commercial hot cell system should be based on future wear rate tests results and failure modes and effects analysis. High wear rates would point to the use of the current removable and reversible designs, moderate wear rates to the semi-fixed design, and low wear rates to the fixed design. Wear rates would be gauged on the life requirements for the system. Comparison of failure modes and effects with known wear rates as a factor would reveal which design is optimum for hot cell use and what tradeoffs are required.

5.4. FIXED CLOSE SIDE SETTING, PRIMARY AND SECONDARY CRUSHERS

5.4.1. Introduction

The close side settings of the primary and secondary crushers are defined by the smallest gap at the bottom of each crusher through which the material must pass to reach the next crushing stage. These close side settings determine at least one dimension of the fragments which pass through and affect the size reduction of the next stage. The designs of both the primary and secondary crushers are such that the close side settings are essentially fixed at initial installation. The components that determine the close side settings are illustrated in Fig. 7. However, they can be changed by removing the entire pitman assembly and replacing the toggles with ones of shorter length. The potential need for adjusting the close side settings to compensate for tolerance stackup in the constructed assembly, the potential need for adjustment due to wear, and the difficulties involved in changing the settings make it desirable to investigate the addition of a variable close side setting to the design.

5.4.2. Function of the Close Side Setting

The primary function of the close side setting on the primary and secondary crushers is to establish the opening at the bottom of the crusher which produces sufficient size reduction for the succeeding stage to perform its operation.

5.4.3. Design Criteria for Close Side Settings, Primary and Secondary Crushers

The main criterion for the primary and secondary crusher close side settings is to ensure crushing to a size which is sufficient for the succeeding stage to perform its operation.

Fig. 7. Simplified illustration of components determining the close side setting (typical of primary and secondary crushers)

5.4.4. Operating Experience

A number of factors, such as pillow block and pushing beam locations, stationary jaw location, and dimensions of machined surfaces, determine the exact magnitude of the close side setting. The stackup of the tolerances on these dimensions resulted in initial close side setting discrepancies. Therefore, for initial installation of both the primary and secondary crusher pitman assemblies, shims (located between the pushing beam and pushing block) were required to obtain the desired close side settings.

During tests to determine the nip angle required for crushing, various close side settings were also tested by the addition or deletion of the shims. The probability of crushing primary crusher product in the secondary crusher was found to increase, as expected, as the close side settings of the primary crusher were decreased.

5.4.5. Advantages and Disadvantages of Variable Close Side Settings

The advantages of variable close side settings are:

1. Allows adjustment for tolerance stackup in the pitman assemblies and reduces the tolerance requirements.
2. Allows adjustment of the product size distribution to enhance crushing in the succeeding stage and to compensate for different fuel types.
3. Allows for adjustment to compensate for wear.
4. Allows the interchangeability of primary and secondary crusher toggles.
5. Eliminates the need to change toggle lengths to adjust the close side setting.

The disadvantages of variable close side settings are:

1. Requires additional component parts.
2. Requires remote devices for changing the close side settings.
3. Increases the complexity of the pitman designs.
4. Provides no assurance that tolerances, product distributions, or wear which cannot be compensated for by close side setting adjustment will not occur.

5.4.6. Discussion

Due to the large number of component parts required for the primary and secondary crusher assemblies, the potential exists for errors in the close side settings which are due to stackup of the tolerances of the parts. These errors are difficult to avoid without considerable reduction of normally allowed tolerances, which can be costly, requires extensive quality assurance surveillance, and may be unnecessary for the function of the components. The desired close side settings can be assured by the installation of simple shims between the pushing beam and the pushing blocks at final installation. After installation, these shims could be fixed permanently in place; additional shims could be installed later to compensate for wear or differences in crushing behavior between types of fuel elements, which may affect the close side settings.

Toggle assemblies and other component parts could be made interchangeable because the shims would compensate for minor differences between the primary and secondary crushers. However, retention of the removability of the toggle assemblies is unavoidable with either fixed or adjustable close side setting designs because of the potential need to repair these assemblies.

5.4.7. Recommendations

5.4.7.1. Design Efforts

The design of shims to adjust the close side settings on the primary and secondary crushers with interchangeable and removable toggle assemblies should be completed for inclusion in the commercial hot cell system.

5.4.7.2. Decision Basis

Since the retention of removable toggle assemblies in the design is mandatory and the addition of shims allows minor adjustments to the close side setting without changing toggles but does not exclude their removability, the addition of shims to the design retains the advantages of both removable toggle assemblies and fixed closed side settings.

5.5. OVERSIZE MONITORING SYSTEM

5.5.1. Introduction

The oversize monitoring system consists of a screener, a flow rate sensor, and an oversize crusher which are arranged as shown in Fig. 8.

The screener (Fig. 9) operates basically as follows. Crushed materials discharging from the tertiary crusher fall onto a 4750 μm mesh vibrating screen. The material passing through the mesh discharges into a cone-shaped housing which directs it into a tube common to both the screener and the oversize crusher for pneumatic transport to a product collection bunker. The material which does not pass through the mesh discharges into a chute leading to the flow rate sensor.

The flow rate sensor (Fig. 10) operates basically as follows. Crushed materials discharging from the screener chute strike an impact

Fig. 8. Oversize monitoring system arrangement

Fig. 9. Cutaway illustration of screener

Fig. 10. Flow rate sensor

cone suspended by a system of beams. The force of the falling particles causes deflection of the beams. The deflection is converted by strain gauges into an electrical signal proportional to the quantity of material. The material then gravity discharges into the oversize crusher.

The oversize crusher (Fig. 11) operates basically as follows. Crushed materials discharging from the flow rate sensor are recrushed between two wear plates and an eccentrically mounted roll. The recrushed material then discharges into the tube common to both the oversize crusher and screener for pneumatic transport to a product collection bunker.

The oversize monitoring system was considered desirable as a means to detect problems in the preceding crushing stages and to produce crushed product sufficiently fine to be acceptable as primary burner feed. Due to operating problems during system tests, the general complexity of the system, and the eventual need for remote fixtures to remove the component parts, it became desirable to investigate the potentials of alternatives.

5.5.2. Function of the Oversize Monitoring System

The primary function of the oversize monitoring system is to ensure that the crushed material size distribution meets the feed requirements for the primary fluidized bed burner.

5.5.3. Design Criteria for Oversize Monitoring System

The following general performance requirements for the fuel element size reduction system were considered applicable in some degree to the oversize monitoring system:

1. Contain all fuel element materials so that bypass of crushing is avoided.
2. Utilize gravity for the flow of crushed materials.

Fig. 11. Cutaway illustration of oversize crusher

3. Avoid holdup of crushed materials, including dusts.
4. Maintain visibility and accessibility to all components.
5. Minimize maintenance requirements.
6. Facilitate remote maintenance.
7. Minimize the requirements for special remote handling fixtures and remote maintenance tools.
8. Use standard interchangeable commercial or designed parts whenever practical.
9. Minimize potential damage to other equipment from failures.

In addition to the above requirements, the screener and oversize crusher had the following specific requirements:

Screener

1. Accept material gravity discharged from the tertiary crusher and separate the oversize material ($\geq 4750 \mu\text{m}$ ring size) from the acceptable material ($\leq 4750 \mu\text{m}$ ring size) in a manner which allows no oversize material to enter the acceptable material stream and $\leq 5\%$ of the acceptable material to enter the oversize material stream.
2. Gravity discharge the acceptable material into the pneumatic transport system.
3. Gravity discharge the oversize product to the oversize crusher.
4. Be designed to demonstrate remote removal and replacement as an assembly.

5. Be fitted with a device that will effect a temporary closure of the UNIFRAME/screener interface to minimize the dispersal of dusts during screener removal and reinstallation.

Oversize Crusher

1. Accept all oversize material plus $\leq 5\%$ of the acceptable material and reduce it to $\leq 4750 \mu\text{m}$ ring size fragments at a rate $\geq 10\%$ of one whole element per 15-minute period.
2. Be designed to demonstrate remote removal as an assembly.

5.5.4. Operating Experience

Initially a perforated plate was tested for use as the screening surface because of the potential improvement in reliability over a wire mesh screen due to the greater strength of the perforated plate. Unfortunately, many of the holes in the perforated plate were blinded by lodged graphite particles. The situation was not significantly improved by chamfering the holes to reduce the length-to-diameter ratio or by replacing the perforated plate with a wire mesh screen. However, blinding was reduced considerably by the addition of a commercially available self-cleaning device. This device consists of a perforated plate with holes sufficiently larger than the largest particle passing through the screen to render blinding of the plate impossible. The plate is mounted beneath the wire mesh screen and supports cylinders which bounce and rotate in the space between the plate and screen to dislodge particles from the screen. Blinding was reduced but not eliminated by the device and increased proportionally to the quantity of material screened, indicating the eventual need for a maintenance plan or alternative to correct this undesirable condition.

During these and subsequent tests, it was found that the screener was discharging greater than 5% of the acceptable product to the oversize

product stream. Changes in the motion generator settings were unable to consistently reduce this screening inefficiency to the $\leq 5\%$ level. The 4760 μm wire mesh screen was temporarily replaced with a 6350 μm wire mesh screen to determine the magnitude of the inefficiency reduction effected by a larger mesh screen. The inefficiency was reduced to $\sim 0.1\%$ but with the obvious results of allowing some +4760 μm unacceptable product to pass through the screen.

The motion generator settings for the 4760 μm mesh screen which minimized its inefficiency resulted in a small residue of oversize product on the screen surface. This was due to the motion of these particles toward the center of the screen imparted at this motion generator setting. In addition to this material holdup, small quantities of dusts were held up on the tops of the spring supports and within the ventilation enclosure transition between the tertiary crusher and the screener housing. Dust containment within the enclosure and the screener housing, however, was complete.

Throughout all of the tests, no mechanical failures of the screen surface, the screener, its component parts, or the housing were detected.

Tests on the oversize crusher revealed that it did not reduce all of the oversize material discharged from the screener to $\leq 4750 \mu\text{m}$. This was attributed to the spring loading of the wear plates which allowed them to be pushed away from the roll by the flow of material between the plates and the eccentric roll. Setting the gaps closer (which would be difficult remotely under the present design) resulted in failure of the material to flow. Size distributions of products which had only been through the tertiary crushing stage compared with size distributions of those which had been through the entire system showed little difference, indicating that the effect of the oversize crushing stage was minimal.

Fuel particle breakage in the oversize crusher product, as expected, was generally higher than that in product which passed through the

screen. However, since fewer particles passed through the oversize crushing stage, the effect on increasing particle breakage in the total product was small.

The oversize rate monitor was not installed in the system because bench tests had shown it to be too sensitive for this application and in need of further development.

5.5.5. Advantages and Disadvantages

Three viable alternatives have been identified for the present oversize monitoring system:

1. Complete omission of the oversize monitoring system, which would give the maximum reduction of component parts.
2. Replacement of the screen with a larger mesh size which, as tests had shown, would minimize blinding and improve efficiency.
3. Replacement of the oversize monitoring system with an appropriately sized grate to remove material which could block the transport line or damage the burner.

5.5.5.1. Advantages and Disadvantages of Omitting the Oversize Monitoring System

The advantages of omitting the oversize monitoring system are:

1. Minimizes the number of component parts required.
2. Does not require additional, special, or complex remote removal devices and tools.
3. Minimizes areas for potential material holdup.

4. Reduces particle breakage.
5. Does not impose height requirements or add to the complexity of the UNIFRAME.
6. Does not require additional cell clearances for remote removal.
7. Increases accessibility to other system components.
8. Minimizes the disposal of contaminated parts.

The disadvantages of omitting the oversize monitoring system are:

1. Increases the probability of pneumatic transport and primary burner failures due to oversize product.
2. Does not provide a means for indicating wear on the tertiary crusher.

5.5.5.2 Advantages and Disadvantages of Replacing Present Screen With a Larger Mesh Size

The advantages of a larger mesh size are:

1. Reduces probability of screen blinding.
2. Reduces particle breakage.
3. Reduces the quantity of acceptable product which is recrushed due to screen inefficiency.
4. Reduces holdup on the screen.
5. Provides an indication of wear on the tertiary crusher (with fully developed rate monitor).

6. Provides some protection against pneumatic transport and primary burner failures due to oversize product.

The disadvantages of the larger mesh screen are:

1. Retains all of the component parts which can fail and decrease the reliability of the system.
2. Retains the requirement for additional, special, and complex remote removal devices and tools.
3. Retains the majority of areas of material holdup.
4. Does not assure reduction of product to $\leq 4750 \mu\text{m}$ size.
5. Retains increased height requirement and complexity of UNIFRAME.
6. Retains the requirement for cell clearances for remote removal and remote removal devices.
7. Retains the decreased accessibility to other system components.
8. Retains the components which eventually require disposal as radioactive waste either from failure or at the end of useful life.

5.5.5.3. Advantages and Disadvantages of Replacing the Oversize Monitoring System with a Grate

The advantages of a grate are:

1. Reduces the number of component parts required.
2. Reduces the requirement for additional, special, or complex remote removal devices and tools.

3. Reduces areas for potential material holdup.
4. Reduces particle breakage.
5. Reduces height requirement and complexity of UNIFRAME.
6. Reduces the requirements for cell clearances.
7. Reduces the disposal of contaminated parts.
8. Increases accessability to other system components.

The disadvantages of a grate are:

1. Increases the probability of pneumatic transport and primary burner failures due to oversize product.
2. Does not provide a means for indicating wear on the tertiary crusher.
3. Grate can blind and require maintenance action.

5.5.6. Discussion

5.5.6.1. Pneumatic Transport and Primary Burner Failures

The present primary burner feed requirements were estimated from previous tests on a smaller diameter burner and the exact limitations on the feed of the current burner are not known. Also, it is not presently known what definite effects small changes in feed size distribution will have on burner operation. If the overall size distribution becomes gradually larger from wear on UNIFRAME components, the transport and fluidization may deteriorate slowly in proportion to the wear. This type of effect should clearly indicate the need for replacement of worn components

long before a catastrophic failure occurred to the burner or the transport system.

Past testing has indicated that fuel particles do not exist as large agglomerates after fuel element crushing. Assuming this to be a continuing case, burner and transport problems from large dense masses of particles are also remote. The burner feed could be monitored periodically by samples taken in the transport system. These samples would show the gradual changes in size distribution expected from wear of UNIFRAME components, large agglomerates of fuel particles, and large changes in size distribution.

At this point, the present design does not guarantee that oversize material will not reach the burner. However, burner tests on these actual products have revealed no problems to date.

5.5.6.2. Wear

Tests to date with unirradiated graphites have not been extensive enough to reveal wear on any of the UNIFRAME components, even those constructed of mild steel. Since wear rates have not been established for either unirradiated or irradiated fuels, wear could only be assumed to be a problem. Inclusion of the oversize monitoring system was a precaution against wear and not an established need.

Wear occurring in the primary and secondary crushers, if serious enough, would result in the inability of the succeeding crusher to crush the material. This material would not continue on to the burner but would become holdup detectable by material balances. Wear occurring in the tertiary crusher would result in a gradual increase in the size distribution of its product. This product, if sent directly to the burner, would probably deteriorate fluidization in proportion to the change in size distribution.

The monitoring system unfortunately has no means to monitor wear in its own components. The results of wear in this system would be expected to have the same effects as unmonitored tertiary crusher wear. It appears that the only means to provide precautions against wear in all components and to determine the exact nature of the feed to the primary burner is to take periodic samples in the transport system.

For a commercial operation gross wear could be measured in the hot cell during scheduled shutdowns. This would allow for adjustments or replacements prior to catastrophic failures, but would not preclude the periodic monitoring by samples.

5.5.6.3. Failures

All of the postulated catastrophic failures to the crushers, such as bearing sizing, toggle fractures, drive failures, and shaft fractures, would probably result in the inoperability of the affected crusher, excessive vibration, shutdown, or other obvious consequences. Since the results of such failures would be immediate and shutdown imminent, they would not require initial detection by a monitoring system to prevent effects on normal burner feed.

Tramp metal from minor failures such as loose screws, bolts, and nuts could either pass through the screener into the transport system or enter the oversize crusher, where it could cause further damage to that component or pass on to the transport system. Tramp metal from the monitoring system itself would have similar consequences. Since tramp metal of sufficient size would not be transportable at velocities used for crushed fuel element materials, it may eventually lead to transport line blockages. This effect would be less devastating and easier to correct than burner failures due to tramp metal. However, the complete exclusion of tramp metal which is transportable cannot be assured in any system. It must be avoided by diligence in all designs, inspections, and preventative maintenance practices.

The reliability of components in series, such as the crushing - oversize monitoring components of the UNIFRAME system, is commonly expressed as $R_s = R_1, R_2, \dots, R_n$, where R_s is the total system reliability and $R_1, R_2, \dots, R_n$ are the individual reliabilities of the components. Therefore, elimination of a component in the series or improvement of a components reliability must improve the reliability of the total system. This is the case for the mechanical reliability of the UNIFRAME. However, if improvements in mechanical reliability change the product characteristics, the true reliability may not, in fact, be improved. This aspect of the system reliability should not be ignored and cannot be sacrificed as an expense of improving the mechanical reliability.

Accessibility to the components of the UNIFRAME to repair failures would probably be improved by simplification or elimination of the oversize monitoring system. This does not eliminate the possibility that the necessary accessibility could be achieved in any design.

The additional penetrations, separations, and remote tooling required for the ventilation enclosure by the present oversize monitoring design increase the probability of failures in these areas. Simplified designs could serve to reduce the probability of these ventilation system failures.

It is possible that failures could occur which would be impossible to repair with the remote tools readily available. This could result in long delays or necessitate removal of the entire UNIFRAME system. These failures are possible with any system but become more likely with complex designs.

5.5.6.4. Remote Fixtures

Presently the designs for remote removal fixtures and tools are not complete. Additional fixtures required for removal of component parts will be subject to failure and require tooling for repairs. Failure of remote tools could render them unavailable for use at required times.

The additional cell floor space required for remote removal of components and the storage area requirements for replacement parts and remote tools cannot be determined until all designs are complete. However, these requirements would be greater and more costly for the more complex and removable components.

5.5.7 Recommendations

5.5.7.1. Wear Tests

The wear tests recommended to establish data for decisions regarding fixed versus removable stationary jaw designs (Section 5.3.6.1) should be conducted in a manner which would provide data to estimate the effects of wear on producing burner feed and to establish guidelines for periodic in-cell wear measurements and component replacement prior to wear out, if required.

5.5.7.2. Sampling

Since any oversize monitoring system will be subject to wear and failure and because the system cannot monitor itself and changes in product size distribution can occur in transport, a sampler should be installed to provide information on these phenomena. The location should be after the UNIFRAME product discharge and compatible with transport and burner requirements.

5.5.7.3. Burner Feed Tests

The present primary burner feed requirements have been estimated and the limitations are not known definitely; therefore, more information is needed for sound design decisions regarding the preparation of feed.

Fueled elements should be used to prepare burner feed by crushing in the UNIFRAME without the oversize monitoring system. These products,

after analysis for size distribution, will provide data on operating parameter differences and problem areas from burning in the primary burner. This should establish the feasibility of using tertiary crusher product as primary burner feed.

5.5.7.4. Design Efforts

5.5.7.4.1. Screening Design. To reduce material holdup on the screen surface, dust retention, and screen blinding, alternatives and design changes should be investigated and tested. Optimum methods should be incorporated into a final screening design.

5.5.7.4.2. Oversize Crusher Design. To reduce dust retention, provide an easily controlled gap setting, and reduce particle breakage, alternate designs and crushers should be investigated and tested if feasible. Optimum designs should be included in the final oversize crusher design.

5.5.7.4.3. Rate Monitor. Alternative methods to measure the quantity of oversize product which remains after tertiary crushing should be investigated and tested. Optimum methods should be included in the monitoring system design.

5.5.7.4.4. UNIFRAME Design. A design which omits the oversize monitoring system entirely should be completed. Also, to avoid the potential problems from tramp metal, all sources such as bolts, nuts, screws, etc., inside the ventilation enclosure should be investigated and avoided in the design or provided with secondary capture such as lock washers, thread compounds, or welding.

5.5.7.5 Decision Basis

The decision between the alternative designs and the present oversize monitoring system must be based on: (1) the suitability or unsuitability

of tertiary crusher product as primary burner feed obtained from actual tests; (2) results of wear tests; and (3) failure modes and effects analysis on all of the completed designs, including effects on the transport system and the primary burner and protection provided by a sampler prior to the burner for all systems.

Unsuitability of tertiary crusher product as primary burner feed, of course, would eliminate installing a grate or removing the oversize monitoring system from consideration as design alternatives because they provide no means of altering the tertiary crusher product. The risk from installing a larger mesh screen and the size of the screen openings can be assessed from burner operating parameter changes and problem areas arising from the unsuitability of tertiary crusher product as feed.

If the tertiary crusher product is found to be suitable for primary burner feed as produced, all alternatives as well as the present oversize monitoring system are viable for further consideration for inclusion in the UNIFRAME system. The need for the oversize monitoring system and the larger mesh screen concept is reduced. However, further assessment based on wear rates and failure modes and effects analysis would be required for the final determination.

If a high wear rate is shown from the tests, a maintenance plan for wear measurement and replacement of components prior to wear out would be formulated. Because the oversize monitoring system components are subject to the same wear conditions and are unmonitored, the downstream sampler and maintenance plans for wear measurement and component replacement are applicable for these components also, regardless of screen size. High wear does not preclude omission of the oversize monitoring system because of these factors.

The need for the present oversize monitoring system and its larger mesh alternative is reduced if wear rates are low, but the failure modes and effects analysis must be used to determine if intolerable conditions exist.

Assuming the tertiary crusher product is suitable for primary burner feed and materials of construction are used which have reasonable wear rates, removal of the oversize monitoring system has a large number of advantages, pending, of course, a favorable failure modes and effects analysis. The grate concept has few advantages since it can only exclude large fragments of graphite and tramp metal, provides essentially no change in the product, must be inspected, and could cause unnecessary blockages from product bridging.

The larger mesh screen in the present oversize monitoring system does improve efficiency, reduce particle breakage, or reduce blinding. It would be preferable to the current screen if it did not cause severe changes in burner operation and other problems, assuming the as-produced tertiary crusher product is unsuitable as feed and thereby excludes omission of the system.

6. CONCLUSIONS

The present fuel element size reduction system design has been proven adequate under "cold" pilot plant conditions to produce feed suitable for burning in a fluid-bed burner. However, prior to commission for a commercial fuel reprocessing facility in a hot cell environment, the design will require upgrading to be compatible with these more severe operating conditions. Some of these design refinements were identified at the onset of the initial design, but were purposely postponed because of budgetary and scheduling considerations and to allow confirmation of design concepts by testing prior to proceeding on the more sophisticated and costly design. Other refinements were discovered through problems encountered in system and component tests. These design requirements are identified as:

1. Modification of the ventilation enclosure to integrate with the machine frame and for compatibility with remote removal.
2. Replacement of current wear surfaces with hardened materials.
3. Provision for a through-the-cell-wall drive system.
4. Provision of start-under-load capabilities.
5. Provision of a fuel loading port.
6. Modification of lubrication systems for compatibility with remote operations and high radiation environment.
7. Provision of interchangeable pitman parts.

8. Provision of a secondary crusher clearing device.
9. Modification or replacement of the oversize crusher to ensure $\leq 4750 \mu\text{m}$ product, remote gap adjustment, and minimum material holdup.

After evaluation with current designs, the following design changes are recommended for the final commercial facility design in addition to a comprehensive review of the entire UNIFRAME design for tramp metal sources:

1. Provide primary crusher with the smallest practicable fixed nip angle $\leq 14^\circ$.
2. Provide shim adjustments for the primary and secondary crushers close side settings.
3. Provide UNIFRAME product sampler.

The following designs are recommended for completion concurrently with wear tests and testing of burner feed prepared without the oversize monitoring system, followed by failure modes and effects analysis for final evaluations:

1. Primary crusher clearing device design.
2. Primary and secondary crushers fixed and semi-fixed stationary jaw designs.
3. Optimum screener design.
4. Alternative rate monitor designs.

7. ACKNOWLEDGMENTS

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APPENDIX
DETAILED DRAWINGS

5210004	Machining Details - Machine Frame
5210007	Pitman Installation
5210009	Stationary Jaw Assembly - Primary Crusher
5210010	Cheek Plate Assembly - Stationary Jaw, Primary Crusher
5210034	Machining - Stationary Jaw, Secondary Crusher
5210035	Fabrication - Stationary Jaw, Secondary Crusher

NOTES:

1. REMOVE BURRS & SHARP EDGES
2. DIMENSIONS & TOLERANCES PER ANSI Y 14.5
3. ITEM 2 (2 PLCS) TO BE WELDED IN PLACE AFTER ITEM 4 IS WELDED.
4. PLUG WELD 4 VENT HOLES & GRIND SMOOTH.
5. CHEEK PLATE ASSYS. ⑥ MUST BE INTERCHANGEABLE FROM ONE FACE OF JAW ASSY. ① TO THE OTHER.

NOTES

- 1. REMOVE ALL BURS & SHARP EDGES
- 2. DIMENSIONS & TOLERANCES PER ANSI-Y14.5
- 3. STRESS RELIEVE BEFORE MACHINING
- 4. EACH SIDE TO BE MACHINED FOR INTER-CHANGEABILITY WITH ITEMS 2 & 3
- 5. MACHINE AT ASSY TO MATE WITH ITEM 16 FOR MAXIMUM SURFACE TO SURFACE CONTACT
- 6. MACHINE AT ASSY TO MATE WITH 521000A SUB FOR MAXIMUM SURFACE TO SURFACE CONTACT
- 7. WELD AFTER MACHINING WITH MIN. AMOUNT BUILD-UP
- 8. MACHINE TO MATE WITH ITEMS 4 & 5 FOR MAX. SURFACE TO SURFACE CONTACT
- 9. ASSEMBLE ITEM 5 ON SHAFT, INSTALL ITEMS 14 & 15 TO FINGER TIGHT ONLY, TO ALLOW ITEM 5 FREE ROTATION ON SHAFT BEFORE WELDING
- 10. HEAT TREAT ITEM 2 & 3 TO 180,000 TO 190,000 U.T.S. HEAT TREAT ITEM 4 & 5 TO 170,000 TO 180,000 U.T.S.

ITEM	DESCRIPTION	QTY	REMARKS
1	5210035-1	1	FRAME - 1" DIA. SHAFT, 1" DIA. SHAFT, 1" DIA. SHAFT
2	5210036-1	1	FLAT WASHER 1" DIA.
3	5210034-1	1	WASHER NUT 1" DIA.
4	5210034-13	1	PLUG 3/4" DIA. BAR
5	5210034-12	1	CLOSURE PLUS ASSY
6	5210034-11	1	STOP 2" DIA. BAR
7	5210034-10	1	SHAFT 1" DIA. BAR
8	5210034-9	1	OPERATING SCREEN ASSY
9	5210034-8	1	CLOSURE BUSH 1/2" DIA. BAR
10	5210034-7	1	UPPER SLEEVE, 1" DIA. BAR
11	5210034-6	1	KEY 3/4" DIA. BAR
12	5210034-5	1	UPPER SHAFT 1/2" DIA. BAR
13	5210034-4	1	UPPER SHAFT 1/2" DIA. BAR
14	5210034-3	1	MAIN SHAFT 1/2" DIA. BAR
15	5210034-2	1	MAIN SHAFT 1/2" DIA. BAR
16	5210034-1	1	FRAME - 1" DIA. SHAFT, 1" DIA. SHAFT, 1" DIA. SHAFT

EST. WT. 1375 LBS. (24-1)
EST. TOTAL WT. 2046 LBS.

1 SHEET OF 2