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HTGR FUEL PARTICLE CRUSHER DESIGN EVALUATION

by
N. W. JOHANSON

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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ABSTRACT

This report describes an evaluation of the design of the existing engineering-scale fuel particle crushing system for the HTGR reprocessing cold pilot plant at General Atomic Company (GA). The purpose of this evaluation is to assess the suitability of the existing design as a prototype of the HTGR Recycle Reference Facility (HRRF) particle crushing system and to recommend alternatives where the existing design is thought to be unsuitable as a prototype. This evaluation has led to recommendations for an upgraded design incorporating improvements in bearing and seal arrangement, housing construction, and control of roll gap thermal expansion.

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1. SUMMARY

This report describes an evaluation of the existing cold pilot plant design for the engineering-scale fuel particle crusher system. The purpose of this evaluation is to assess the suitability of the existing design as a prototype of the HTGR Recycle Reference Facility (HRRF) particle crusher system and to recommend alternatives where the existing design is thought to be unsuitable.

2. INTRODUCTION

As a part of the National HTGR Fuel Recycle Development Program, under the direction of the Department of Energy (DOE), General Atomic Company (GA) has responsibility for the development, using unirradiated fuels, of a High-Temperature Gas-Cooled Reactor (HTGR) fuel reprocessing pilot plant which is prototypical of a proposed HTGR Reference Recycle Facility (HRRF).

The overall objective of the HTGR Fuel Recycle Development Program is to demonstrate the technology for recycle of HTGR fuels by using the Th/U-233 fuel cycle for the future safe operation of a commercial recycle plant.

The fuel in an HTGR of the 2000- to 3000-MW(t) size consists of TRISO coated fissile particles and BISO coated fertile particles, as described in an earlier report (Ref. 1). The flowsheet for reprocessing HTGR fuel, shown in Fig. 1, is based upon a crush-burn-leach head-end operation with intermediate classification of fissile and fertile particles. These steps are followed by a second crush-burn-leach operation on the TRISO coated fissile particles, a Purex solvent extraction process to recover fissile U-235, and an Acid-Thorex solvent extraction process to recover and separate bred U-233 and fertile thorium (Ref. 2).

Equipment and process demonstrations will be performed on a cold pilot plant scale at GA to obtain the data for the design and operation of the HRRF. The pilot plant includes the head-end processes of crushing, fluid-bed combustion, pneumatic classification, and particle crushing,

Possible modification of the existing dry head-end cold pilot plant engineering-scale equipment to obtain reliable and maintainable equipment that is prototypical of the HRRF design has required an evaluation of the

Fig. 1. HTGR fuel reprocessing

existing equipment design. This evaluation has taken into account performance, cost, ease of implementing changes, and the impact of such changes on the current HRRF design. Feasible alternative designs have been similarly evaluated. The prototype design resulting from this and any subsequent evaluations should be capable of performing all required functions at the lowest present worth cost when extrapolated over the life of the HRRF.

The method of achieving these objectives included the development of information in the following sequence:

1. Preliminary System Definition. The limits of the system were established based on similarity to the current HRRF design. Features which serve only a development testing function, such as certain instrumentation or sampling equipment, were excluded.
2. Functional Level Diagram. The hierarchy of functional relationships between the system and its constituent parts was graphically displayed.
3. Functional Analysis System Technique (FAST) Diagram. The basis and secondary functions of important design features and the interactions among these functions were graphically depicted. This technique aided in evaluating the effectiveness of particular hardware items.
4. Definition of Scope of Evaluation. The number of design features to be evaluated was limited to those mandated by basic process requirements or HRRF facility requirements.
5. Evaluation of Present System Design. The present (cold pilot plant) design of the particle crusher system was evaluated with respect to its satisfaction of current technical specifications and other requirements such as operability, maintainability, and reliability.

6. Selection and Evaluation of Alternative System Designs. Ideas, concepts, and designs were generated as alternatives to those present design features that have real or potential problems or that represent relatively high capital cost or operating expense. These alternatives were then reduced to the best two or three capable of meeting the same technical specifications and constraints as the present design.
7. Comparison of Present and Alternative Systems. A simple ranking system, including subjective assessments of performance and cost, was used to compare the present design features and the best alternatives.

Before selection of the features of the present design to be evaluated, discussions of problems experienced or expected were conducted with cognizant persons (see Acknowledgments) in the areas of design, engineering, purchasing, manufacturing, quality assurance, installation, and operation. Many common problems were revealed, such as the magnitude of manufacturing tolerances and methods of fabrication. These problems were consolidated, and affected hardware items and their basic functions were identified.

After these discussions were concluded, the sources of the requirements for the salient features were identified as shown in Table A-1 of Appendix A. Source categories included basic process requirements, remote maintenance requirements, and facility [Allied Chemical Corporation (ACC), GA, HRRF] requirements. Those features that resulted solely from ACC or GA facility requirements were then excluded from the scope of the design evaluation. The remaining five features, listed below, then constituted the scope of the design evaluation:

1. Roll gap adjustment
2. Roll gap thermal expansion control
3. Bearing design
4. Seal arrangement
5. Housing design

3. FUEL PARTICLE CRUSHER DESCRIPTION

The GA double-roll fuel particle crusher is shown schematically in Fig. 2.

Fuel particles enter the roll crusher by gravity flow from the feed bunker. The crushing action is produced by the contact between the two counter-rotating roll surfaces and the fuel particles, which forces the fuel particles through the narrow gap between the rolls. The crushed fuel particles are discharged by gravity into the secondary burner feed hopper. The rolls, driven by a variable-speed gear drive system, are contained in an enclosed, sealed housing which prevents loss of fuel particles, fragments, and dust.

In normal operation, the drive motor is activated, the drive control is set for the desired roll RPM (read on a speed indicator), and the rolls are allowed to reach the desired speed. The fuel particles are batch-charged by opening a knife gate valve in the discharge outlet of the feed bunker and are choke-fed by gravity to the crushing area, where the silicon carbide coatings of the particles are fragmented. The crushed material is then discharged into the burner feed bunker.

Fig. 2. GA double-roll particle crusher

4. EVALUATION OF THE PRESENT SYSTEM

The principal functions of the five selected design features of the present fuel particle crusher system were derived from FAST diagrams (Appendix B) and are listed in Table A-1. The advantages and disadvantages of each of these features of the present system are listed in Table A-2. Most of the existing crusher design features are able to perform the principal functions for which they were designed. The chief problems generally involve difficult fabrication, complex maintenance, difficult installation, or high cost.

5. ALTERNATIVES

After evaluation of the present system had been completed, value engineering techniques were used to generate new ideas, designs, and methods for achieving the functions performed by the existing design features. The generation of new ideas was carried out without the imposition of any design constraints in order to enhance freedom of thought and to maximize the number of potential alternative designs. New ideas were generated in a session including the author and five other persons who had been personally involved in various aspects of the design fabrication, installation, and operation of the engineering-scale particle crusher (see Acknowledgments).

Once a number of ideas had been conceived for each design feature, constraints and technical specifications were applied against them. In addition, ideas with similar or compatible features were combined. The aim was to reduce the number of alternatives for further evaluation to a maximum of two or three. Then the advantages and disadvantages of each remaining alternative were compiled.

6. COMPARISON OF ALTERNATIVES AND THE PRESENT SYSTEM

In order to compare the alternatives against the present systems, a simple ranking system was employed. The attributes which were considered to be the most important were assigned a weighing factor (between 1 and 10) as a measure of their relative importance. Then the present system and the alternatives were assigned a subjective value between 1 (= poor) and 10 (= excellent) (with 5 = fair). The attributes which were considered in the ranking comparisons were performance, reliability, maintenance, operability, and initial cost.

The performance attribute is defined as the ability of the crusher to produce acceptably crushed feed with a minimum of unbroken particles. The performance is assumed to be directly related to the accuracy of the roll gap. The reliability attribute is a measure of the system's ability to sustain a period of successful operation. The maintenance attribute is a relative measure of the ability to return the system to operation and also includes consideration of the special facility or equipment required to perform maintenance on high level contaminated equipment. The operability attribute considers the complexity of operating the equipment and the impact a particular feature may have on that complexity. Initial cost is a self-explanatory attribute.

If in evaluating certain features no differences were found to apply for a particular attribute, it was eliminated.

6.1. DESIGN FEATURE NO. 1: ROLL GAP ADJUSTMENT

6.1.1. Discussion

The performance of the double-roll particle crusher is related directly to the ability of the design to establish and maintain a uniform, accurately sized, and stable gap through which fuel particles are forced to break their SiC coating. The initial fabrication of fuel particles results in a range of sizes. The Fort St. Vrain (FSV) TRISO fertile particle is nominally about 630 μm (0.0248 in.) with a range of ~ 500 to ~ 850 μm . If the roll gap is set larger than the smallest particle, the crushed product will contain an increasing fraction of unbroken particles as the gap increases, as shown in Fig. 3(a). If the roll gap is set too narrow, the product size distribution (and average particle size) will become increasingly smaller, as demonstrated in Fig. 3(b), and unacceptable as secondary burner product feed. As a consequence, the roll gap must be accurately established. For the FSV fertile particle, measurements by GA (Ref. 3) indicate that the gap must be no smaller than 0.470 mm (0.0185 in.) to produce acceptable burner feed. Measurements by Allied Chemical Corporation (ACC) (Ref. 4) indicate that a gap larger than 0.483 mm (0.019 in.) will produce unbroken particle fractions in excess of the 1% design criterion. For a FSV fertile particle, it is necessary to maintain a nominal 0.470-mm (0.0185-in.) gap accurate to 0.013 mm (0.0005 in.). The consequences of this fact are that:

1. A precision crusher of very rigid construction is required.
2. Wear must be kept to a minimum by judicious choice of materials to obtain an economic operating lifetime.
3. Since a temperature difference of 8°C between the rolls and housing will change the gap by 1/2 mil, some form of thermal control will be required to ensure stable performance.

Fig. 3(a). Effect of roll clearance on percent of unbroken particles in roll crusher product (data from Ref. 4)

Fig. 3(b). Effect of roll gap on particle average volume-surface diameter (data from Ref. 3)

6.1.2. Reference Design

The reference design is a fixed gap roll crusher. The design is shown in Fig. 4. Two precision ground 102-mm (4-in.) diam. rolls are supported by tapered roller bearings located in 85-mm (3.346-in.) diameter bores in two hardened side plates. The gap accuracy is established by close tolerance positioning of the bores in the side plates and grinding of the rolls to very low runout. This basic accuracy is maintained by the rigid construction of the crusher. The reference crusher is not designed to be a maintainable entity in a radioactive facility. At the end of its wear-out life, the crusher is to be discarded and replaced by a new unit.

6.1.3. Alternatives

6.1.3.1. Adjustable Gap (ACC) Design (Alternative No. 1). The adjustable gap particle crusher design is significantly more complex in construction than the current fixed gap design. Figures 5 and 6, showing adjustable gap designs developed by ACC and Oak Ridge National Laboratory (ORNL), clearly reveal the complexity of construction. The main advantages of the adjustable gap crusher are its capacity to compensate for roll wear and its ability to deal with multiple particle sizes with a single crusher. On the negative side, the advantages of an adjustable gap are partially offset by the need for precision gap measurement instrumentation and control. The ability to measure and control a gap of approximately 0.495 mm (0.0195 in.) to ± 0.013 mm (± 0.0005 in.) between two 102-mm (4-in.) diameter rolls requires an extremely accurate measurement technique. Since roll wear is an important consideration, the gap must be measured directly rather than indirectly (e.g., by position of adjustment screw). That this can be readily accomplished in the hot cell environment is not certain. The adjustable roll crusher contains approximately twice as many parts as the fixed gap crusher and consequently its reliability will be lower.

Fig. 5. ACC adjustable gap double-roll crusher (Ref. 4)

Fig. 6. ORNL adjustable gap double-roll crusher (Ref. 5)

6.1.3.2 Split Housing Design (Alternative No. 2). The split housing design is a concept which marries the better features of the current fixed gap design and an adjustable gap design such as the ACC design. As shown in Fig. 7, the crusher would consist of two roll housing modules and a shim spacer. The simplicity and ruggedness of the design would retain the essential reliability of the fixed gap design, while the modular aspect would provide a roll gap adjustment capability for initial set-up and subsequent wear compensation.

By extending the usable lifetime of the roll crusher, the design reduces capital cost, but its major cost benefit may be in the reduction of high level contaminated waste quantities.

6.1.4. Evaluation

In order to evaluate the two alternative design features against the reference design, the desired attributes were listed, and each design was then ranked on a scale of 0 to 10, with 10 being the highest desirability. The result of this ranking is shown in Table 1. The basis of performance was considered to be gap accuracy and stability. Since the fixed gap is set up very accurately at assembly and consists of rigid construction, it is considered to provide the best performance. The modular assembly feature and the adjustable gap feature were ranked at somewhat lower values because of the lower mechanical rigidity and somewhat reduced accuracy of gap setting. For reliability, the reference design and the modular assembly design (of similar complexity) are assumed to be approximately equal, whereas the adjustable gap crusher is ranked significantly lower because of its greater complexity.

The maintenance of the reference design is ranked high since it is predicated merely on a discard and replace philosophy at the end of its natural wear-out life. However, the adjustable gap and the modular assembly design features permit gap adjustment, causing maintenance operations to be more complex. The modular assembly design will require transfer to a maintenance cell where disassembly and gap change operations can be

Fig. 7. Split housing (modular) design

TABLE 1
ROLL GAP ADJUSTMENT - COMPARISON OF PRESENT AND ALTERNATIVE DESIGNS

Attribute	Weight	Reference Design	Alternative No. 1	Alternative No. 2
Performance	10	8 (80)	5 (50)	7 (70)
Reliability	10	5 (50)	3 (30)	5 (50)
Maintenance	10	8 (80)	5 (50)	5 (50)
Operability	10	10 (100)	5 (50)	10 (100)
Initial cost	5	7 (35)	3 (15)	10 (50)
Total points		345	195	320

performed, and consequently it is ranked lower than the reference design. On a maintenance basis, the adjustable crusher is considered to be on par with the modular assembly concept.

In terms of operation, the reference design and the modular assembly design are ranked equally high. The difficulty associated with accurate in-cell gap adjustment of an adjustable roll crusher for different size particles results in its receiving a significantly lower ranking.

The modular roll assembly concept is considered to have an edge in initial cost since lower positional accuracy is required for the side plate bore which houses the roll bearing, and it is therefore ranked highest. The greater quantity of parts and the more complex assembly indicate that an adjustable roll concept will carry a significant cost penalty, and it is consequently ranked well below the reference design.

6.1.5. Summary

The results of the ranking of the three designs (reference and two alternatives) are shown in Table 1. The weighted ranking tends to favor the reference design over the two alternatives.

6.2. DESIGN FEATURE NO. 2: THERMAL EXPANSION CONTROL

6.2.1. Discussion

An inherent problem in the utilization of any double-roll crusher design is its sensitivity to temperature difference between rolls and housing. As discussed in the prior section, the performance of the double-roll crusher is dependent on the gap accuracy. The very narrow gap is a result of the difference between two much larger dimensions (bearing center-to-center distance and roll diameter) as shown in Fig. 8. Consequently, the gap accuracy can be adversely affected by a temperature difference between the housing and the rolls. For a roll gap accuracy of 0.013 mm (0.0005 in.), the maximum permissible temperature difference between the rolls and the housing is 8°C. This temperature difference is small, considering available sources of heat. At the rolls, heat is being added to the surfaces by mechanical crushing of the particles, friction between the feed column and the rolls, fission product decay heat, temperature difference between incoming feed and the rolls, and bearing heat generation. Housing heating originates primarily from bearing heat and fission product decay heat. Temperature difference may also occur because of the differences in transient response between the rolls and housing.

6.2.2. Alternative

A proposed design feature is the addition of a solid center core of copper to conduct heat axially out of the rolls, as shown in Fig. 9. The heat would then be dissipated by cooling fins to the cell atmosphere or by conduction to a water or gas cooled heat sink.

6.2.3. Evaluation

Excessive heating of the rolls relative to the housing reduces the gap and causes overcrushing of particles. The current tight gap requirements are based on FSV fertile particle tests. Since weak acid resin (WAR)

Fig. 8. Roll gap geometry at 20°C

Fig. 9. Roll cooling core

fiissile particles have a tighter size distribution and different fluidization characteristics, it may be feasible to allow overcrushing to a greater degree with these particles, thereby permitting a smaller gap and obviating the thermal control requirement. If the temperature difference is critical, however, the thermal control alternative feature is required.

6.3. DESIGN FEATURE NO. 3: BEARING DESIGN

6.3.1. Discussion

The bearing design for the reference (fixed roll) crusher is illustrated in Fig. 10. The roll is supported at each end by a Timken tapered roller bearing. The inner race of the bearing is mounted on the roll shaft with a medium press fit and the outer race is lightly pressed into an 84.99-mm (3.346-in.) diameter bore in the housing side plate. To eliminate play, a preload is applied to the bearing by insertion of a piece of shim stock between the bearing cover plate and the outboard face of the outer race. Although this design has permitted accurate gap control and good performance, a number of areas for improvement, listed below, have been identified based on discussions with personnel involved in particle crusher design and development:

1. Process for preloading bearings is cumbersome and does not produce consistent results.
2. High preload is required to obtain a stable gap dimension between the rolls. This results in 81.3 to 122 N·m (60 to 90 in.-lb) of running torque.
3. Bearing is not available with a shield. Contamination and lubricant retention are problems.
4. Differential axial thermal expansion brought about by temperature gradients between the roll and housing can significantly increase the preload with the potential for bearing damage.

Fig. 10. Bearing configuration for reference roll crusher

5. Bearing arrangement is intolerant of housing distortion and requires high precision fabrication and assembly.

6.3.2. Alternative

An alternative bearing feature is pictured in Fig.11. The rolls are supported at each end by tapered bore cylindrical roller bearings. The inner race is mounted to the shaft with a tapered sleeve. By simple adjustment of a threaded collar, the tapered sleeve is expanded into the inner race, eliminating bearing play. The outer race is lightly pressed into the housing. One bearing is axially fixed (Fig.11, right side) and the other is of an axially "floating" design (Fig.11, left side), thereby compensating for differential thermal expansion in the direction of the roll axis between the rolls and housing. This type of bearing can be fitted with a shield to minimize contamination and retain lubrication.

6.3.3. Evaluation

Rankings of the reference design and the alternative are given in Table 2. Performance, maintenance, and operability attributes are expected to be equivalent for both bearing configurations. However, the alternative bearing design is expected to have a distinct advantage in reliability through elimination of the thermal effect on preload and also through improvement of bearing cleanliness and lubricant retention resulting from a bearing shield. The alternative design will also have a slight advantage in initial cost because of simplification of the bearing cover plates and of the assembly and preload procedure.

6.4. DESIGN FEATURE NO. 4: SEAL

6.4.1. Discussion

The space between the roll ends and the inboard surface of the housing side plates is approximately 0.10 mm (0.004 in.) wide and forms a natural dirt trap. During particle crushing of SiC fragments, carbon and heavy

Fig. 11. Alternate bearing design

TABLE 2
BEARING DESIGN - COMPARISON OF PRESENT (REFERENCE) AND ALTERNATIVE FEATURES

Attribute	Weight	Reference Design	Alternative
Performance	10	8 (80)	8 (80)
Maintenance	10	8 (80)	8 (80)
Reliability	10	5 (50)	8 (80)
Operability	10	10 (100)	10 (100)
Initial cost	5	7 (35)	8 (40)
Total Points		345	380

metal fines are produced, some of which, without a seal, would migrate to and contaminate the bearing, causing rapid bearing deterioration and short crusher life.

The current design utilizes a set of cast iron seal rings (Fig. 12) which float inside matched opposing grooves machined in the roll ends and side plates. Problems observed with the reference design are:

1. Significant contamination of bearing lubricant is occurring, indicating seal ring bypass.
2. Improper groove location tolerances and differential thermal expansion can cause seal ring drag (and sometimes breakage) from radial shear load on the ring.
3. Seal ring and slot precision designs complicate fabrication and assembly and increase cost.

6.4.2. Alternatives

6.4.2.1. Face Seal (Alternative No. 1). This design is depicted in Fig. 13. A static graphite, soft metal, or polymer ring is pressed against the face of the roll by a disc spring.

6.4.2.2. Nilos Seal (Alternative No. 2). This is a special German-manufactured bearing shield which is assembled on the bearing, as shown in Fig. 14, and provides an additional barrier to migration of material into the bearing.

6.4.2.3. Modified Seal Material (Alternative No. 3). Replacement of the cast iron ring with a softer, more elastic material may improve sealing and reduce breakage potential and drag. Possibilities include Teflon and Polystyrene.

Fig. 12. Reference roll crusher seal design

Fig. 13. Face seal (alternative No. 1)

Fig. 14. Nilos seal (alternative No. 2)

6.4.2.4. Precision Feeder Chute With Trickle Feed (Alternative No. 4).

Redesigning the feeder chute to fit the rolls more precisely (see Fig. 15) in combination with trickle feeding will allow the particle crushing to be contained in the center of the rolls, and therefore very little fines will be presented to the space between roll ends and side plates.

6.4.2.5. Purge (Alternative No. 5). Addition of a purge port to the bearing cover plate would permit a pressure differential and a small flow to oppose migration of contaminants into the bearing space (Fig. 16). The purge port could also be combined with any of the other alternative ideas to further improve sealing.

6.4.3. Evaluation

None of the seals have any effect on roll gap accuracy, and consequently they are all ranked equally in performance, as shown in Table 3. The reliability of the crusher is expected to be significantly enhanced by substitution of the face seal, and thus the face seal is ranked an 8 versus a 5 for the reference current design. Alternatives No. 2 through 5 are judged superior to the present design but slightly inferior to the face seal in reliability.

The present design and alternatives No. 1 through 4 are considered equal with respect to maintenance. The gas purge (alternative 5) is ranked low because of the additional disconnect complexity.

For operation, alternatives No. 1 through 4 are considered equivalent to the present seal arrangement. Alternative No.5 (purge) adds additional complexity to the operation requiring the control and monitoring of purge gas and is therefore ranked lower.

Fig. 15. Precision feeder chute

Fig. 16. Bearing gas purge

TABLE 3
SEAL DESIGN - COMPARISON OF PRESENT (REFERENCE) AND ALTERNATIVE DESIGNS

Attribute	Weight	Reference	Alternative No. 1	Alternative No. 2	Alternative No. 3	Alternative No. 4	Alternative No. 5
Performance	10	8 (80)	8 (80)	8 (80)	8 (80)	8 (80)	8 (80)
Reliability	10	5 (50)	8 (80)	6 (60)	7 (70)	6 (60)	7 (70)
Maintenance	10	8 (80)	8 (80)	8 (80)	8 (80)	8 (80)	6 (60)
Operation	10	10 (100)	10 (100)	10 (100)	10 (100)	10 (100)	8 (80)
Initial cost	5	<u>7 (35)</u>	<u>8 (40)</u>	<u>6 (30)</u>	<u>7 (35)</u>	<u>5 (25)</u>	<u>6 (30)</u>
Total points		345	(380)	350	365	345	320

On an initial cost basis, the face seal (alternative No. 1) is expected to have the lowest cost; alternative No. 4 (precision feeder chute with trickle feed) would be the most costly. The other seal designs will fall between these extremes and are ranked appropriately.

Based on the total ranking, the face seal (alternative No. 1) is slightly preferred.

6.5. DESIGN FEATURE NO. 5: CRUSHER HOUSING

6.5.1. Discussion

The crusher housing must be of sturdy construction to withstand the radial crushing loads with minimum deflection. A compact design is dictated by the need for minimum process material holdup and for reduction of the cost associated with disposal of contaminated equipment, assuming a replace/discard maintenance philosophy. Operating costs will also be reduced by minimizing initial capital cost with this maintenance philosophy, considering the relatively short anticipated lifetime (perhaps several weeks).

The current engineering-scale crusher was designed to verify the fixed roll gap design but was never optimized to reduce initial capital costs. The design, shown in Fig. 17, consists of five basic pieces. The two side pieces which support the rolls are machined of AISI-D2 tool steel and are heat treated to RC 58-60 to minimize wear. The end plates and the top cover are machined weldments constructed of A36 carbon steel. The problems associated with the current housing are identified as follows:

1. The high precision required to establish accurate fit-up of the five parts necessitates multiple machining and grinding operations and results in a very expensive design.
2. Slight distortion in the housing from assembly operations (variations in bolt-up, etc) has an adverse effect on bearing reliability.

Fig. 17. Current (reference) crusher housing construction (bolts and dowels not shown)

6.5.2. Alternatives

6.5.2.1. Two-Piece Cast Housing (Alternative No. 1). Housing fabrication assembly and cost would be greatly simplified by reducing the housing to the two-piece construction illustration in Fig. 18. The housing is composed of two identical castings of nodular cast iron with a longitudinal parting plane. After machining of the mating surfaces at the parting plane, the castings are assembled and doweled, and the large bores and critical surfaces adjacent to the rolls are machined. Machining and assembly operations are much simpler than those of the present design.

6.5.2.2. Machined Two-Piece Housing (Alternative No. 2). Simplification could also be achieved by machining of mating halves from a solid block, as shown in Fig. 19. This design would have virtually the same benefits as the cast housing (alternative No. 1). Therefore, the preferred design would essentially be dictated by the quantity required and the production costs.

6.5.3. Evaluation

The three designs are ranked in Table 4. Both of the alternative designs are judged to be superior to the reference housing design in terms of performance and reliability criteria. The rigidity and dimensional stability of the alternative designs should result in superior roll gap control. Lower housing distortion will contribute to improved bearing reliability.

Maintenance is judged to be about equal for all cases.

Both alternative designs have the potential for significantly lower initial cost than the reference construction. Since the crusher maintenance is based on direct replacement and discard, the low initial cost will contribute to reduced operating costs. Both alternative designs are ranked higher in overall benefit than the reference design. For prototyping purposes and small quantities, the two-piece machined housing would prevail, whereas for the quantities required in commercial operation (HRRF), the two-piece casting would be the preferred design.

Fig. 18. Two-piece cast housing design

Fig. 19. Two-piece machined housing

TABLE 4
HOUSING DESIGN - COMPARISON OF PRESENT AND ALTERNATIVE DESIGNS

Attribute	Weight	Reference Design	Alternative No. 1	Alternative No. 2
Performance	10	7 (70)	8 (80)	8 (80)
Reliability	10	5 (50)	7 (70)	7 (70)
Maintenance	10	8 (80)	8 (80)	8 (80)
Initial cost	5	7 (70)	10 (100)	10 (100)
Operation	10	<u>10 (100)</u>	<u>10 (100)</u>	<u>10 (100)</u>
Total points		370	(430)	(430)

7. INTEGRATED DESIGN

After evaluation of each of the five features and comparison of the current design against proposed alternatives, it is desirable to recommend an integrated design which would combine the best features of the various designs. The integrated design recommended here is the proposed next generation fuel particle crusher, and, with suitable remote interfaces, it represents an HRRF compatible prototype.

The integrated design is shown in Fig. 20. The design maintains the fixed (non-adjustable) gap design of the current crusher. The housing is a two-piece casting which will substantially reduce manufacturing complexity and unit cost. The bearing design consists of cylindrical roller bearings with tapered collars and dust shields. One bearing is of a floating design to permit axial thermal expansion of the roll. The ring seal of the current crusher is replaced by a spring-loaded face seal. Addition of a purge between the bearing and the seal is also proposed to minimize bearing contamination. Finally, if the fissile particle size distribution and the fluidization characteristics of the crushed particles warrant very accurate gap control, a thermal control feature will be added to remove heat generated at the rolls and minimize thermal gradients.

Fig. 20. Integrated design

8. ACKNOWLEDGMENTS

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9. REFERENCES

1. Young, Derrell T., "The Use of Fluidized Bed Combustion in HTGR Fuel Reprocessing," General Atomic Report GA-A13748, November 1975.
2. Baxter, B. J., G. E. Benedict, and R. D. Zimmerman, "Flowsheet Development for HTGR Fuel Reprocessing," in Proceedings of the A.I.Ch.E. Symposium on Gas-Cooled Reactor Fuel Cycles, August 29 - September 1, 1976, Atlantic City, N. J.
3. "Fuel Particle Crushing - Activity Plan Phase I Completion," General Atomic Company, unpublished data.
4. "Experimental Testing of a Roll Crusher for Breaking Silicon Carbide Coatings on Ft. St. Vrain Fuel Particles," Allied Chemical Corporation Report ICP-1070, April 1975.
5. "Progress and Status Report, September 1966," Oak Ridge National Laboratory Report ORNL-4026, October 6, 1966.

APPENDIX A
SCOPE OF EVALUATION AND EVALUATION OF PRESENT SYSTEM

TABLE A-1
SCOPE OF EVALUATION

Function	Subsystem Component/ Part	Feature	Source of Requirement				
			Process	Remote Maintenance	Facility		
					ACC	GA	HRDF
Fracture thickness	Rolls	Gap adjustment	X	X			
Apply force	Bearings	1. Drag (during operation)	X				
		2. Protection from particle wear	X	X			
		3. Thermal expansion (interface with housing)	X	X			
Reduce losses	Crusher housing	Method of construction (one-piece)	X				
Reduce losses	Bearing cover plates		X	X			
Reduce losses	Seal ring	Drag (during operation)	X				
Convert energy	Drive	Power level (1 HP) (start under load)	X				

TABLE A-2
EVALUATION OF PRESENT SYSTEM

Feature	Advantages	Disadvantages	Design Specifications/ Remarks
Roll Gap Adjustment (Ref: fixed gap)	Few parts; simple and reliable No indication of gap setting required Compact and inexpensive	Cannot compensate for gap wear; shorter life More spares required Requires high precision in fabrication Separate crusher for each particle	
Roll Gap Thermal Expansion Control (Ref: no thermal control in present design)	Simpler and more reliable Less expensive; requires fewer support systems	Gap dimension control is inadequate for some fuel particles	
Bearing Design (Ref: tapered roller bearings with opposed pre-load)	Zero clearance Relatively inexpensive Adjustment for bearing wear	Pre-load process difficult and not completely repeatable Pre-load is thermally unstable Bearing requires separate shield Lubrication is difficult High running torque	

TABLE A-2 (Continued)
EVALUATION OF PRESENT SYSTEM

Feature	Advantages	Disadvantages	Design Specifications/ Remarks
Bearing Seal Arrangement (Ref: cast iron rings in machined grooves)	Reduces ingress of process material into bearing Radiation resistance	Requires precision machining of roll ends and crusher housing Variations in tolerance cause roll drag Sensitive to radial expansion Seal rings have poor reliability due to low flexibility	
Crusher Housing (Ref: five-piece doweled assembly)	Detail part fabrication is simple Permits using material combinations Compact	Assembly/disassembly is difficult and not consistent Sealing is difficult Interactive effects can shorten bearing life	

APPENDIX B
FUNCTIONAL ANALYSIS SYSTEM TECHNIQUE (FAST) DIAGRAMS

Fig. B-1. FAST diagram for crusher housing, bearing cover plate

Fig. B-2. FAST diagram for particle crusher system

APPENDIX C
FUNCTIONAL LEVEL DIAGRAM

SYSTEM:

SUBSYSTEM:

ASSEMBLIES:

COMPONENTS:

Fig. C-1. Functional level diagram