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INTERIM DESIGN REPORT: FUEL PARTICLE CRUSHING

interim

by

J. W. BAER, J. B. STRAND, E. J. COOK,
and C. M. MILLER

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ABSTRACT

General Atomic Company (GA) has the responsibility for the development and operation of a HTGR fuel reprocessing pilot plant for unirradiated fuels. In the head-end processing of the fuels in the pilot plant, after the fertile and fissile fuel particles are separated, the silicon-carbide-coated particles are crushed to break the carbide coatings and expose the thorium and uranium kernels and the inner carbon coatings for fluid bed burning.

The double-roll fuel particle crusher discussed in this report was developed to fracture the silicon carbide coatings of Fort St. Vrain (FSV) fertile and fissile and large high-temperature gas-cooled reactor (LHTGR) fissile fuel particles. The report details the design task for the fuel particle crusher, including historical test information on double-roll crushers for carbide-coated fuels and the design approach selected for the cold pilot plant crusher, and shows how the design addresses the equipment goals and operational objectives. Design calculations and considerations are included to support the selection of crusher drive and gearing, the materials chosen for crushing rolls and housing, and the bearing selection. The results of the initial testing for compliance with design objectives and operational capabilities are also presented.

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1. 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 Thorium Utilization 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.

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 systems include the head-end processes, in which unirradiated fuels are reduced in size by crushing, element and matrix graphites are removed by fluid-bed combustion, fissile and fertile particles are separated by pneumatic classification, and silicon carbide coatings are broken in a particle crusher to expose the inner carbon coatings and fuel for subsequent fluid-bed combustion.

This report describes the design requirements, the design, and the test results to date of the FSV fuel particle crusher development for the fuel reprocessing pilot plant.

The double-roll fuel particle crusher described herein is shown schematically in Fig. 1-1.

Fuel particles enter the fuel particle roll crusher by gravity flow from the particle crusher feed bunker. The crushing action is produced by

Fig. 1-1. Double-roll particle crusher

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 enclosure which connects the crushing system to the particle crusher feed bunker and the secondary burner feed hopper and prevents loss of fuel particles, fragments, and dust. The configuration of the rolls and the enclosure assembly precisely determines the crushing gap between the rolls and assures that all of the fuel particles will pass through the roll gap. The roll gap can only be altered by replacing the rolls with rolls of different diameters.

In normal crusher operation, the drive motor is activated, the drive controller 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 particle crusher feed bunker, and the fuel particles 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.

2. DESIGN FACTORS

2.1. GENERAL REQUIREMENTS

The requirements which determine the final design of the Fuel Particle Roll Crusher will be based upon (1) the design requirements of the HTGR HRRF, (2) the future requirements applicable to a commercial HTGR fuel reprocessing facility, (3) the present and future regulatory and safety requirements, (4) conditions unique to the crushing of fuel particles, and (5) test results.

Using as a basis knowledge derived from work at GA and work done by others on fuel particle crushing, a design criteria document for the crusher was prepared (Appendix A of this report). This publication documented specific requirements for (1) equipment performance, (2) safety and health, (3) materials safeguards, and (4) interfacing within the system. Its objective was to provide criteria for a design which would be as prototypical for actual hot-cell equipment as was practicable in a cold pilot plant. The initial design of the fuel particle crusher had to meet as many of the objectives as possible within the constraints of initial budget and schedules. Planned equipment upgrading based on tests of the initial fuel particle crushers and additional knowledge will result in a prototypical design of the fuel particle crusher for hot cell operation.

2.2. EQUIPMENT DESIGN REQUIREMENTS

The following are equipment design requirements which are applicable to the fuel particle crusher:

1. Accepts Fort St. Vrain fertile and fissile and LHTGR fissile fuel particles and fractures the outer silicon carbide coating

to expose the thorium carbide and uranium carbide and the inner carbon coatings for fluid bed combustion.

2. Crushes fuel particles on a semicontinuous basis in 60 kg batches at a minimum rate of 30 kg/hr.
3. Uses gravity feed from a particle crusher feed bunker and discharges by gravity into a secondary burner feed bunker.
4. Limits unbroken fuel particles in the crushed product to a maximum of 1% and minimizes particles bypassing the crushing rolls.
5. Minimizes material holdup and fuel particle losses within the crusher.
6. Is capable of starting under fully loaded conditions.
7. Is sealed to operate at an internal pressure of 5 psig and in a hot cell environment up to 115°F.
8. Has materials of long-wear life with tolerance for the operating environment of a hot cell.
9. Is capable of inert gas blanketing or of separate gas purging.
10. Possesses a minimal total volume as regards the disposal of contaminated waste.
11. Uses standard commercial components, materials, and processes wherever possible.
12. Possesses as a design objective the improvement of the normal service life, reliability, and availability of the equipment

through substitution of more suitable materials, seals, or bearings when tests indicate the need.

2.3. OPERATIONAL REQUIREMENTS

The following are operational requirements for the particle fuel crusher:

1. Is adaptable to remote operation and maintenance and suitable for high radiation environments.
2. Possesses maximum radioactive material accountability.
3. Provides adequate measures to eliminate or minimize the effects of any credible industrial hazard including hazards from pyrophoric materials.
4. Is compatible with administratively controlled radiation exposure and operating restrictions for the use of natural and depleted uranium and thorium compounds.
5. Incorporates adequate features for personnel protection from radiation and airborne radioactive materials and from exposure to radiation and other industrial hazards.

3. TESTS

3.1. BACKGROUND TESTS

3.1.1. General Atomic Tests

GA has tested double roll crushers for fragmenting unirradiated, silicon-carbide-coated fuel particles since 1970, when a crusher was purchased to a GA specification (Ref. 3-1). Subsequently, GA continued fuel particle crushing tests with double roll crushers in support of the Thorium Utilization Program under Contract AT (04-3)-167 for the San Francisco Operations Office of AEC and Contract E(04-3)-167 for the San Francisco Operations Office of ERDA. The results of these tests are included in the GA Thorium Utilization Program quarterly reports commencing in March 1972 and in GA-A13540, "Interim Development Report for Secondary Burning," (Ref. 3-2).

Particle crushing tests at GA were done in crushers having 3-in. diameter by 1-in. wide smooth crushing rolls with a fixed center distance. The crushing gap was not adjustable. A single motor was used to drive both rolls.

3.1.2. Oak Ridge National Laboratory Tests

Roll crushing of silicon-carbide-coated, unirradiated Peach Bottom (PB) HTGR fuel was studied at Oak Ridge National Laboratory (ORNL) using a commercial, double-roll crusher with 8-in. diam by 2-in. wide smooth steel rolls. This work was reported by Whatley in 1965, in ORNL-3958 (Ref. 3-3). This led to the testing of an improved crusher design having 12-in. diam by 4-in. wide smooth rolls. Both crushers had an adjustable crushing gap between the rolls and each was driven by a single motor. This testing was reported in 1966 in ORNL-3968 (Ref. 3-4) and ORNL-4026 (Ref. 3-5).

3.1.3. Idaho National Engineering Laboratory Tests

Crushing tests of unirradiated Fort St. Vrain carbide-coated fertile and fissile fuel particles were performed by Allied Chemical Corp. at Idaho National Engineering Laboratory (INEL) for ERDA using a double-roll crusher. This machine had 4-in. diam by 1-1/2-in. wide smooth-faced rolls with an adjustable roll gap and a variable-speed single-motor drive (Refs. 3-6 and 3-7).

3.2. TEST RESULTS

3.2.1. Summary

The crushing tests collectively demonstrated that the double-roll crusher with smooth-faced rolls could effectively fracture the unirradiated silicon-carbide coatings of fuel particles without creating excessive fines at the desired throughput rates for plant-scale processing and commercial operations. The size distribution of the crushed product was satisfactory for stable fluidization characteristics in the secondary burner and did not contain unbroken particles in excess of the desired <2 wt %.

3.2.2. Testing Information

The testing provided the following information:

1. The size of the gap between rolls required to produce satisfactory burner feed.
2. A means for reliably and repeatedly gauging the roll gap using soft solder.
3. Roll sizes and face characteristics, surface hardnesses, and roll speeds.

No reliable wear data were obtained by crusher tests at ORNL, INEL, or GA. A summary of pertinent information is given in Table 3-1.

Design and operations personnel at GA, through meetings and design conferences, used the available test data and information to develop a list of design requirements, Appendix B of this report, and the design criteria, Appendix A of this report, for a fuel particle crusher for use in the fuel reprocessing pilot plant.

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- 3-5. "Status and Progress Report, September 1966," Oak Ridge National Laboratory Report ORNL-4026, October 6, 1966.
- 3-6. Palmer, W. B., "Experimental Testing of the Double-Roll Crusher for Breaking Silicon Carbide Coatings on Unirradiated Fort St. Vrain Fuel Particles," Allied Chemical Report ICP-1070, April 1975.
- 3-7. Ring, R. L., and W. B. Palmer, "Experimental Testing of the Double-Roll Crusher for Breaking Fort St. Vrain Fissile Particles," Allied Chemical Report ACI-189, October 1975.
- 3-8. Rickman, W. S., "Process Guidelines for Fuel Particle Crushing," General Atomic Company unpublished data, April 8, 1975.

TABLE 3-1
SUMMARY OF EXPERIMENTAL FUEL PARTICLE CRUSHERS

Org	Size (Diam x Width)	Type	Roll			Speed (rpm)	Gap		Fuel ^(a) Type	Drive Motor	Throughput (kg/hr)	Data Source
			Face	Material	Rc		Type	Size (in.)				
GA	3 x 1	Double roll	Smooth	1040	60	29 Single speed	Fixed	0.012 0.017	FSV	1	~10	Ref. 3-8 Ref. 3-2
ORNL	8 x 2	Double roll	Smooth	Unknown	Unknown	Unknown	Variable	--	PB	1	Unknown	Ref. 3-3
	12 x 4	Double roll	Smooth	ASTM O-2	60	Variable	Variable	--	PB	1	~30 at 762 μ m ~10 at 51 μ m	Ref. 3-4 Ref. 3-5
INEL	4 x 1-1/2	Double roll	Smooth	ASTM D-2	60	Variable	Variable	0.012 (max)	FSV - fissile	1	~6 at 70 rpm ~23 at 120 rpm	Ref. 3-7
	4 x 1-1/2	Double roll	Smooth	ASTM D-2	60	Variable	Variable	0.018 (max)	FSV - fertile	1	~11 at 40 rpm	Ref. 3-6

(a) FSV = Fort St. Vrain fuel.
PB = Peach Bottom fuel.

4. DESIGN DESCRIPTION

The fuel particle crusher for the cold pilot plant is a small, compact, double-roll crusher with a fixed crushing gap. The crusher operates semicontinuously in line with the solids handling system to produce feed for the secondary burner (Fig. 4-1). Figure 4-2 shows the functional assembly of the fuel particle crusher.

The particle crusher 5200002-1 comprises two principal interdependent systems, the crusher drive and the crushing module 5211006-1. Both are on the top cover of the secondary burner feed hopper 5247104-2, with the top of the crusher coupled directly to the air classifier storage bunker 5201500. The crusher is gravity-fed and discharged and it operates under choke-fed conditions, producing a minimum of 30 kg/hr of fragmented silicon-carbide-coated particles. The design matrix (Fig. 4-3) subjectively identifies the equipment and operational requirements addressed by each crusher group, assembly, and functional component.

4.1. CRUSHER DRIVE

The drive for the particle crusher uses the drive motor 5200002-5 mounted directly onto the speed reducer 5200002-4. The output shaft of the reducer carries the drive pinion gear 5200002-3, which powers the two counter-rotating roll drive gears, 5211011-5.

The drive requirements were calculated for a double-roll crusher with two 4-in. diam by 4-in. long crushing rolls operating at 40 rpm to crush silicon-carbide fuel particles having an average size of 630 microns for a maximum of 50 kg/hr from a batch feed. (See Appendix E, Sections E-1 through E-6.)

Fig. 4-1. Fuel particle crusher and drive motor (mounted on 20-cm secondary burner hopper)

Fig. 4-2. Functional assembly diagram, fuel particle crusher

COMPONENT OR ASSEMBLY

REQUIREMENTS AND OTHER CONSIDERATIONS		DRIVE GROUP						ROLL GROUP				HOUSING GROUP			
		DRIVE SYSTEM	CRUSHER MODULE 5211006-1	DRIVE MOTOR 5200002-5	DRIVE CONTROLS (COMMERCIAL)	SPEED REDUCER 5200002-4	DRIVE PINION 5200002-3	ROLL GEARS 5211011-5	CRUSHING ROLLS 5211011-3, -4	SEAL RING 5211011-6	BEARINGS 5211006-9	BEARING SHIMS 5211010-3	BEARING COVERS 5211010-1, -2	TOP COVER PLATE ASSEMBLY 5211007-1	SIDE PLATE ASSEMBLY 5211009-1
EQUIPMENT	PARTICLE SIZING, CRUSHING EFFICIENCY	◇	◇			◇	◇	◇		◇	◇	◇		◇	
	CRUSHING RATE	◇	◇	◇		◇	◇	◇							
	GRAVITY FLOW, IN-LINE ASSEMBLY	◇	◇										◇	◇	◇
	1% UNBROKEN PARTICLES & MIN. BY-PASS		◇					□		○	◇	◇	◇	□	
	LOAD CAPACITY & RESTART CAPABILITY	○	◇	○		○	○	○		◇					
	SEALING (INT & EXT), INTERNAL PRESSURE, TEMPERATURE (INT & EXT) INERT GAS USE		◇						◇			◇	◇	◇	◇
	MATERIALS - WEAR LIFE, COST, FABRICABIL- ITY, OTHER SPECIAL CONSIDERATIONS		◇				◇	◇	○	◇	◇		◇	○	◇
	MINIMUM VOLUME FOR FUNCTION (THROW- AWAY CONCEPT)		◇				◇	◇	◇	○	◇	◇	◇	○	◇
	COMMERCIAL PARTS, OR COST IMPACT FEATURES	◇	◇	◇	□	□	◇	◇	◇	◇	□			□	◇
RELIABILITY, RADIATION TOLERANCE		◇								◇					
OPERATIONAL	ADAPTABILITY FOR REMOTE MAINTENANCE	□	◇	◇		◇	□	□							
	MATERIAL ACCOUNTABILITY, MIN. HOLD-UP MIN. LOSSES		◇						◇				◇	◇	
	PERSONNEL PROTECTION, INDUSTRIAL HAZARDS & RADIATION HAZARDS		◇				◇	◇							
	INTERFACE CONSIDERATIONS	◇	◇	□		◇							◇	◇	◇

LEGEND

- FIRST IMPORTANCE
- NEXT IMPORTANCE
- ◇ LESSER IMPORTANCE

Fig. 4-3. Fuel particle crusher design matrix

4.1.1. Drive Motor

With a single-drive motor and assuming an average fuel particle crushing strength of 12.6 lb, the calculated power required ranged from 0.18 hp to 2.2 hp, depending upon the selected roll speed and the particle distribution in the crushing cavity. (See Appendix E, Section E-6, Horsepower Calculations and Summary.) At a throughput of 50 kg/hr and a roll speed of 40 rpm, the required power ranged from 0.26 hp to 1.6 hp. For 1.6 hp, a close-packed and nested crushing cavity with all the particles in the crushing cavity being crushed simultaneously was assumed. This worst condition is considered to be highly improbable.

To review the power requirements for particle crushing, the drive system and the power required for the 3-in. experimental roll crusher were examined. This crusher had a 1/2-hp motor driving double rolls that produced approximately 10 kg of crushed product per hr. Power demand tests conducted at full load and at start-under-load conditions indicated that the unit was overpowered at 1/2 hp (test data is unpublished). Power calculations for this crusher using the same bases as for the prototype crusher indicated a need for less than 1/4 hp assuming close-packed particle crushing. (See Appendix E, Section E-7, Calculations for 3-in. Experimental Crusher.) This is in agreement with the power measurement tests.

The crusher drive system selected for the prototype design was powered with a 3/4-hp electric motor mounted on and driving a speed reducer rated at 1 hp. The system could be upgraded to a 1-hp system by simply exchanging the 3/4-hp motor for a 1-hp motor, since both have the same frame and identical face mounting to the speed reducer. The motor chosen was direct-current, variable speed to permit testing of the crusher at various roll speeds, loads, and crushing rates.

4.1.2. Speed Reducer and Gearing

The balance of the drive system consists of a speed reducer and gear train that can drive the rolls at the desired speed with sufficient power to crush fuel particles at the required rate. Another major requirement for the gearing is the consideration for remote maintenance. Since the combined motor and reducer were to remain in place on top of the burner feed hopper 5247104-2 and the crushing module 5211006-1 with the roll drive gears was to be removable as a unit for replacement or maintenance, the gearing arrangement and the gear tooth form became important.

Two gear train arrangements were investigated for driving the crusher: (1) a direct drive into one of the two intermeshed, counter-rotating roll drive gears; and (2) a pinion drive wherein the pinion powers one of the two roll gears. Both arrangements, shown in Fig. 4-4, would use straight spur gears, and both offer flexibility in the selection of disengagement and removal modes for remote handling. The pinion gearing arrangement was selected for the pilot plant crusher because it had slightly more flexibility.

4.1.2.1. Speed Reducer. The choice of a speed reducer was influenced by the required output torque, speed, and reduction ratio for each candidate gearing arrangement. For the pinion gear drive, the overhung load capacity of the reducer was considered since there would be no bearing outboard of the pinion gear. Table 4-1 summarizes the motor and reducer needs for both drive arrangements, assuming a reasonable set of load conditions, i.e., conditions other than worst-case conditions. Table 4-1 and calculations for the drive (Appendix E, Section E-8) show that the overhung load capacity of each of the reducers is satisfactory. The 1-hp reducer (56E30) provides adequate output torque whereas the 3/4-hp reducer (56D30) is underpowered for the demand of 0.88 hp. Since a 3/4-hp electric motor which was interchangeable with a 1-hp motor had been chosen, it was desirable that a reducer possessing the same flexibility be selected. Table 4-1 shows that the 56E40 reducer used with a 6-in. pitch diameter

DIRECT DRIVE

PINION DRIVE

Fig. 4-4. Candidate gear train arrangement for the fuel particle crusher

TABLE 4-1
SUMMARY OF DRIVE OPTIONS - 2341 LB CRUSHING LOAD
MOTOR SPEED - 1750, ROLL SPEED - 60 RPM

System	Requirements				Reliance A108 (Ref. E-4) Reducer Selection				Reliance A108 (Ref. E-4) Reducer-Actual		
	Roll Demand (hp)	Reducer		Max Tooth Load (lb)	Size	Reduction Ratio	Motor Size (hp)	Over- hung Load Capacity (lb)	Torque Out (in.-lb)	Speed Out (rpm)	HP Out
		Output (rpm)	Torque (in.-lb)								
Direct drive	0.88	60	721	180	56E30	30:1	1	1350	819	58	0.76
					56D30	30:1	3/4	970	595	58	0.55
Pinion drive 4 in. PD	0.88	60	722	361	56E30	30:1	1	1350	819	58	0.76
					56D30	30:1	3/4	970	595	58	0.55
6 in. PD	0.88	40	1083	361	56E40	40:1	1	1340	1050	44	0.73
					56E40	40:1	3/4	1360	777	44	0.54

(PD) pinion and 4-in. PD roll gears has this capability. Therefore this reducer and gear train with straight spur gears were chosen. This selection provided flexibility for disengagement and removal of the crushing module.

4.1.2.2. Drive Gears. The drive pinion and the mating roll gears have gear teeth (T) with the standard 20 deg pressure angle (PA) involute tooth form. This tooth form was selected over the 14-1/2 deg PA tooth because of its greater load capacity. The data displayed in Fig. 4-5 are typical horsepower ratings for steel and cast iron spur gears. The data are plotted for gear sizes, numbers of teeth, and tooth forms which are representative of the gears under consideration for the particle crusher. Also shown in Fig. 4-5 are the required horsepower at the maximum and typical operational roll speeds. Extrapolating to a roll speed of 40 rpm (the speed of the roll gears), the load capability of a spur gear is 1.4 hp with 20 deg PA teeth, 8 diametral pitch (DP), and 32 teeth. This is more than two times the assumed demand load of 0.63 hp at 43 rpm (see Appendix E, Horsepower Summary in Calculations, Section E-6). Thus a service factor of 2.2 can be used based upon the gear manufacturer's ratings.

Calculations were made for the strength of the 20 deg spur gear tooth (Appendix E, Section E-9) under dynamic loading on the 6-in. PD and factored for speed, gear materials, tooth form, mounting, and alignment. These calculations indicated that a 1-in. wide gear face was satisfactory. However, calculations for gear wear life indicated that a 1-in. face was inadequate and that heat treated steel gears may be required. Commercial steel gears with 1-1/4-in. wide faces were chosen for the pilot plant crusher.

4.2. CRUSHING MODULE

The crushing module 5211006-1 consists of the crusher housing, two roll assemblies, and the roll drive gearing. It is functionally prototypical of the HRRF requirements. The module establishes a fixed and

Fig. 4-5. Horsepower ratings for 0.40 carbon steel spur gears

preset roll crushing gap which remains within narrow tolerance limits during operation. The crushing operation is totally enclosed in a sealed housing which is mounted in line with the solids transport system and the secondary burner system and is designed to tolerate the temperature, pressure, and radiation environment of a hot cell.

The crushing module has a clean and unobstructed interior which fits closely at the top and ends of the crushing rolls, precluding entrapment of all but minimal quantities of throughput material and preventing bypassing of the rolls; it also assures complete materials accountability. The module design anticipates no adjustment of roll positions during operation, the fixed roll gap having been established and controlled by the design and manufacturing of the crusher. Disassembly, repair, and adjustment or replacement of crusher components after exposure in service are not considered feasible; therefore replacement of the complete crusher is planned, when required. This has dictated a design which facilitates remote removal and replacement of the crushing module, with consideration of remote handling, storage, and minimum volume for disposal of contaminated materials and replaced assemblies.

The crushing module is disengaged from the crusher drive and removed as a unit from its position between the particle crusher feed bunker and the secondary burner feed bunker. Removal and replacement by remote means is by horizontal or vertical disengagement and translation.

The roll gears, rolls, and bearings are sized to crush fuel particles having an average size of 630 microns at the maximum rate of 50 kg/hr, with less than 1% unbroken particles and with the ability to start crushing with a full crushing cavity.

4.2.1. Crusher Housing

The housing of the crusher module is of bolted and welded steel construction and consists of a top cover plate 5211007, side plates 5211009,

and end plates 5211003. The housing encloses and positions the hardened steel crushing rolls and establishes the fixed crushing gap. It further creates side plates for the crushing cavity, shrouds the crushing operation, and mounts and positions the roll bearings. The housing directs the feed material to the crushing gap and has hopper and bunker mounting flanges for assembly in the solids transport and the secondary burner systems.

The side plates 5211009 of the crusher housing mount the precision-tapered roller bearings of the crushing rolls and accurately position the rolls to the desired crushing gap. The side plates are hardened tool steel, Rc 58 to 60, and act as cheek plates for the crushing cavity. The top cover plate 5211007 positions the side plates and the feeder tube relative to the crusher rolls and is machined to create bypass guards at the top of each roll, preventing uncrushed feed material from circumventing the rolls. An integral part of the cover plate is the feeder tube and coupling flange used to attach the crusher to the feed bunker. The feeder tube projects into the crushing cavity, directing the feed material to the rolls and controlling the material flow under choke-fed conditions. The frame end body plates 5211003 complete the enclosure of the crushing cavity, and, along with the side plates, have mounting flanges for assembly of the crusher module onto the secondary burner feed hopper.

The five-piece construction of the crusher housing permits the parts requiring no hardening (the top and ends) to be made inexpensively as mild steel weldments. The side plates, however, must be hardened in the areas around and between the end positions of the crushing rolls to combat abrasive wear from crushed particles. Selective area hardening was ruled out because it presented problems with dimensional stability of the part and with the machining of the seal ring slot.

D-2 tool steel was selected for the side plates because it has excellent dimensional stability after heat treatment to the required

hardness. This choice permitted final machining of the ring slots and dowel pin holes prior to final heat treatment, with other final machining accomplished by grinding after heat treatment. The D-2 tool steel is also a satisfactory selection for abrasive wear resistance as it possesses the essential attributes for such applications; it is heat treatable to a high initial hardness, it will work-harden, and it has a high carbon content. (See Section 4.2.2.2.)

4.2.2. Roll Assemblies

Two roll assemblies, 5211011-1 and -2, are used in the pilot plant particle crusher. One is a reference roll of inexpensive carburizing-grade carbon steel (C1018) and the other a roll of the readily available candidate alloy steel 4340.

The rolls 5211011-3 and -4 are surface-hardened and precision-ground, with the roll diameter and runout controlled to assist in maintaining the roll crushing gap to a tolerance of 0.001 in. The inner cones of the tapered roller bearings 5211006-9 are axially mounted on the roll shaft. Extensions of the roll shaft are used for mounting the roll gears 5211011-5, which are stock straight spur gears with 20 deg PA tooth form. Each end of the rolls adjacent to the side plates has cast iron seal rings 5211011-6, which nest in mating slots in the side plates 5211009. These seal rings effect a rotating, sliding seal to protect the roller bearings from the crushed material. The end clearance between the rolls and the side plates is maintained by ground faces on the top cover plate. Bearing cover plates 5211010 with shims are used to position the outer cups of the tapered roller bearings, to obtain precise bearing preload and to eliminate bearing radial clearance.

4.2.2.1. Crusher Rolls. Both crushing rolls, 5211011-3 and -4, are of one piece construction with integral drive shafts to facilitate manufacturing and to provide strength and rigidity. They are surface-hardened to identical depths and hardnesses (0.060 to 0.070 in. and Rc 58 to 60).

Hardened roll sleeves, although practical for special cast alloy roll surfaces, are not used for the cold pilot plant crushing rolls, for which rolls with hardened heat-treated surfaces were chosen. The rolls used by GA, ORNL, and INEL in the double roll crushers they tested were made from a variety of materials, all heat-treated to a high (Rc 60) surface hardness. (See Table 3-1.)

4.2.2.2. Roll Materials - Wear Resistance. The wear resistance of materials for crushing rolls has been the object of extensive study by Climax Molybdenum Co. and others in support of their ore and rock crushing operations, by operatives in mineral dressing, and by the earthmoving and grinding wheel industries. Abrasive wear is generally thought to be one of three kinds, according to Borik in Ref. 4-1:

1. Low stress abrasion or scratching such as that encountered in conveyor lines, pumping mineral slurries, and earthmoving. Stresses are insufficient to crush materials.
2. High stress abrasion, also known as grinding abrasion, involving two wearing surfaces in a gritty environment which crush abrasive particles entrapped between them. A mild impact is usually present. A typical example is the ball mill.
3. Gouging abrasion, wherein the abrasive materials cut into the wearing surfaces, producing gouges, and remove large particles of material. Either the hammer or bar mill experiences gouging abrasion accompanied by high impact. The jaw crusher experiences gouging abrasion accompanied by low to intermediate velocity impact.

It was deemed that the fuel particle crusher would be subjected to abrasive wear more severe than the high stress grinding ring but less severe than gouging abrasion in fracturing the highly abrasive silicon-carbide particle coatings.

Climax Molybdenum Co. showed in their abrasive wear tests (Ref. 4-1) that in both high stress abrasion and gouging abrasion, the abrasion resistance of the crushing surfaces is a continuous function of the "work hardened hardness." The more severe type, gouging abrasion, requires that wear surfaces be made from materials which are martensitic in structure, of a high carbon content, and high initial hardness. The materials chosen for the pilot plant particle crusher rolls were: (1) A.I.S.I. 4340, a wrought, chromium-nickel-molybdenum steel alloy, surface-hardened to Rc 50 to 60; and (2) A.I.S.I. 1018, a carburizing-grade carbon steel, carburized and hardened to a surface hardness of Rc 58 to 60. Both selections meet most of the criteria for wear-resistant materials in gouging or high stress abrasive service.

Borik and Scholz (Ref. 4-2) state that ". . . the gouging wear resistance of SAE 4340 steel quenched and tempered at 400°F (205°C) . . . is comparable to most of the classical austenitic manganese type steels." They also state that this resistance results from the martensitic structure in the heat-treated 4340. The Hadfield steels, which are of the austenitic manganese kind, are widely used in the mining industry where grinding and gouging abrasion are encountered.

Figure 4-6 from data in Ref. 4-2 shows the relationship of wear rate to carbon content and to hardness for typical materials. This figure shows that tempered 4340 is only slightly less resistant to gouging abrasion than all the white cast irons which are preferred materials for gouging abrasion. The influence of the high initial hardness and the in-service work hardening of heat treated 4340 is shown in Fig. 4-6. The high initial hardness makes 4340 superior to the Hadfield steels in wear resistance but slightly inferior to the white cast irons. In-service work-hardening of the heat treated 4340 does not appear to improve its wear resistance. The companion roll in the particle crusher to the 4340 roll is made of A.I.S.I. 1018 which was carburized, producing a surface carbon content higher than that of 4340. This increased carbon content permits surface hardening to the required Rc 58 to 60 and greatly improves the wear resistance rate.

(a)

(b)

Fig. 4-6. Wear rate versus carbon content (a) and wear rate versus hardness (b); source: Climax Molybdenum (Ref. 4-2)

All roll materials considered were judged suitable to operate in the highly radioactive environment of a hot cell and would be unaffected by other in-cell conditions.

4.2.2.3. Roll Calculations. The size of crushing rolls for the cold pilot plant was a scale-up from the GA experimental crusher (Ref. 4-3). The scale-up assumes that a straight line relationship exists between roll speed and crusher product throughput, per Palmer (Ref. 4-6). Thus an increase in throughput to the required 50 kg/hr necessitated a roll crushing face 4-in. wide, operating at a speed of nearly 40 rpm (4 in./1 in. long x 40/30 rpm = 5.3 factor). This roll diameter is in agreement with Palmer's test rig (Ref. 4-6).

Using the established roll length, diameter, and materials, the approximate length and seat diameter of the bearings, a reasonable shoulder fillet radius, and Peterson's Chapter 3, "Stress Concentration Factors," (Ref. 4-4), the stress concentration which results from the fillet at the change in diameter from the bearing mounting diameter to the crushing diameter can be calculated. Using this stress concentration factor, the fatigue strength of the roll can be found for each roll and material. (See Appendix E, Roll Design Calculations, Section E-10.) From these calculations the working stress for the 1018 carbon steel roll was determined to be 11,500 psi and for the 4340 alloy steel roll, 23,000 psi.

The maximum deflection (sum of maximum shear deflection plus maximum bending deflection) for each roll under a uniformly distributed crushing load can also be determined (Ref. 4-5). The safe operating stresses used in these calculations are the working stresses determined above for 1018 and 4340 steels. The shaft loads are calculated from these stresses and from an arbitrary stress concentration factor of 2.5. (See Appendix E, Section E-10.) The maximum deflection found for the 1018 steel roll was 0.0002 in.; for the 4340 steel roll it was 0.0004 in. Actual deflections based upon actual crushing loads are negligible since these loads are a maximum of 7560 lb, assuming the worst-case conditions, as compared to the 28,900 lb used in the above deflection calculations.

It can be shown (see Appendix E, Section E-10) that the temperature effects are significantly more influential in the size of the crushing gap than are the load effects. A rise to an equilibrium temperature of 115°F will decrease the roll gap by 0.002 in.

4.2.2.4. Bearings. The particle crusher for the cold pilot plant required bearings of a capacity which would minimize the bearing influence on the precision of and the retention of the preset roll crushing gap during the crushing operations. This required a precision bearing with capability for adjustment to remove radial clearances and for radially preloading during installation. The bearings, in addition to having adequate radial load capacity and reliability, had to be compact (of thin profile) and reasonably priced.

The three types of bearings considered were sleeve, ball, and roller bearings with tapered, spherical, and cylindrical rolls. Sleeve bearings were eliminated because of their limits in size, capacity, precision, and adjustability.

Table 4-2 shows nine candidate ball and roller bearings and their characteristics considered during trade-off determinations. From these bearings, the single-row tapered roller bearing was chosen since the tapered rolls and roll races allow ready adjustment to remove radial clearances and to radially preload the bearing by advancing the roller assembly (cone) into the outer conical race (cup). Additionally its split design permits assembly of the cones onto the roll shaft and of the cups into the side plates, facilitating mounting and separability. The main disadvantage of this type bearing is that integral seals or shields, features which are available in most nonseparable bearings, are not obtainable with this design.

The single row, tapered roller bearing is available in three precision classes, in addition to the commercial bearings: Class 00, Class 0, and Class 3, in order of decreasing precision. Arbitrarily, Class 0 bearings

TABLE 4-2
CANDIDATE BALL AND ROLLER BEARINGS

Bearing Description	Source ^(c)	Radial Capacity (lb)	Physical Dimensions			Separability O.D./I.D.	Precision Bearing	O.D. Runout (Class 5 or Equiv.) (in.)	Rigidity Scale	Radial Clearance (0.0001 in.)	
			O.D.	I.D.	Width					Low	High
1. Super precision, single row, deep groove ball bearings	1	6070	3.5433	1.9685	0.7874	No	Yes	0.0006	Fair	1	5
2. SKF filling slot type of NDH loading groove, single row ball bearings ^(a)	1	7950	3.5433	1.9685	0.7874	No	No	0.0004	Fair	1	5
	2	5050	3.5433	1.9685	0.7874	No	Yes				
3. Super precision angular contact ball bearings - single row NDH	1	5800	3.5433	2.1654	0.7087	No	Yes	0.0006	Fair	1	5
	2	4850	3.5433	1.9685	0.7874	No	Yes	0.0004			
4. Super precision angular contact ball bearings - duplex mounted	1	9410	3.5433	2.1654	1.4173	No	Yes	0.0006	Excellent	1	5
5. Double row deep groove ball bearings	1	9220	3.5433	1.9685	1.1875	No	No	0.0006	Good	1	5
	2	8084	3.5433	1.9685	1.1875	No	Yes	0.0004			
6. Super precision cylindrical roller bearings - double row	1	11800	3.5433	2.1654	1.0236	No	Yes	0.0006	Good	10	17
7. Spherical roller bearings	1	14700	3.5433	1.9685	0.9055	No	No	0.0006	None	10	17
8. Single row tapered roller bearings ^(b)	1	14800	3.5433	2.1654	0.9055	Yes	No	0.0003	Fair	0	0
	3		3.3465	2.0000	0.6875	Yes	Yes	0.0003			
9. Cylindrical roller bearings - single row	1	8440	3.5433	1.9685	0.7874	No	No	0.0006	Fair	10	17
	2	6460	3.5433	1.9685	0.7874	Yes	Yes				

^(a) Shielding and low radial clearance available.

^(b) Adjustable radial clearance

^(c) Sources: 1 = SKF Industries Inc.
2 = New Departure Hyatt bearings, General Motors Corp.
3 = The Timken Company

were obtained for installation. This class and Class 00 are sold with matched cup and cone elements for greater tolerance control.

In the particle crusher, the bearing cone elements are assembled on the roll shafts and their matching cups are assembled into the side plates. When assembled into the crusher housing, the bearings are adjusted by axially positioning the bearing cover plates with shims to remove bearing clearances and to obtain the desired bearing radial preload. The amount of preload is determined by the amount of torque required to rotate individual roll shafts.

Sealing of the roll bearings to retain lubricants and to prevent the entrance of foreign material into the bearing presented a significant problem. Precision crushing indicated a need for a large diameter shaft with the largest feasible bearings to reduce deflections. This resulted in a narrow annular area at the end of the roll between the bearing outside diameter and the crushing surface. Thus, the design required a small, simple, effective, and inexpensive sealing arrangement which would be unaffected by the nuclear and thermal environment.

The solution was to use self-lubricating cast iron seal rings located close to the roll periphery, half seated in the roll and half seated in the side plate in slots. This ring and slots form a labyrinth seal, blocking crushed material from the bearings and preventing bearing lubricant from entering the crushing cavity.

In the design of the pilot plant particle crusher, no provision was made for the lubrication of the bearings other than initial grease packing. Little information was available on the lubrication needs of the crusher, considering the indeterminate life cycle, the unknown effectiveness of the ring seal, and the unknown effect of the nuclear and thermal environment in the crusher. Operation of the crusher will provide knowledge for lubrication of advanced crusher designs.

REFERENCES

- 4-1. Borik, F., "Using Tests to Define the Influence of Metallurgical Variables on Abrasion," Metals Eng. Quart. 12, 2, (1972) p. 33.
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- 4-3. Rickman, W. S., "Process Guidelines for Fuel Particle Crushing," General Atomic Company unpublished data, April 8, 1975.
- 4-4. Peterson, R. E., Stress Concentration Design Factors, John Wiley & Sons, Inc., New York, 1953.
- 4-5. Larke, E. C., The Rolling of Strip, Sheet, and Plate, The MacMillian Co., New York, 1957.
- 4-6. Palmer, W. B., "Experimental Testing of the Double-Roll Crusher for Breaking Silicon Carbide Coatings on Unirradiated Fort St. Vrain Fuel Particles," Allied Chemical Report ICP - 1070, April 1975.

5. DESIGN VERIFICATION

To determine that the fuel particle crushers for the cold pilot plant satisfied the design and operational requirements of the design criteria (Appendix A), two crushers were manufactured. Each crusher was supplied with spare rolls of different diameters for varying the roll crushing gaps as required for crushing the three types of fuel to be used in the tests.

The test objectives, description, and acceptance criteria are defined in the activity plan (Appendix C) of this report. Criteria for obtaining wear rate data, particularly on the rolls, were not to be within the scope of the activity plan acceptance tests because of the handling difficulties and the cost of fuel particles. Such data will be provided from normal crushing operations conducted to provide feed for the secondary burner.

The fuel particle crushers were tested for compliance of the design to the acceptance criteria defined in the activity plan, Appendix C. In Table 5-1 the numerous criteria from the design criteria document, Appendix A, are detailed together with comments as to method and measure of compliance.

TABLE 5-1
DESIGN CRITERIA COMPLIANCE
DC 520001

Criterion	Requirement	Comment
Fracture of carbide coatings	Demonstrate	Demonstrate with FSV fissile, fertile, and WAR particles
Semicontinuous operation	Demonstrate	
Throughput	30 kg/hr (min)	Operate at 30 to 150 kg/hr
Gravity feed and discharge	Demonstrate	Vertical, in-line design
Start-under-load	Demonstrate	
Material accountability	Maximize	Unobstructed, clean, sealed interior
Min material hold-up and losses	0.5% (max)	} Per activity plan requirements
Positive dust seal	5 psi (max)	
Unbroken particles	1% (max)	
Crushing efficiency	Maximize	
Material bypass	Minimize	Min clearance at roll ends and tops; no bypassed material detected in product
Mean particle size	160 μ m (min)	Per activity plan requirements
Remoteability	Adaptable	Throwaway module, flexibility as designed for disconnect and disassembly
Radiation environment	Tolerance	All metallic materials except grease
Thermal environment	115°F (max)	OK for all materials
Seismic RDT STD F9-2T	Compliance	Meets Category III
Systems interfacing	18 in. height 2 in. inlet 4 x 4 in. outlet	All requirements met
Inert gas blanketing	Capability	
Effects of industrial hazards and pyrophoric materials	Minimize	Incorporated into design

TABLE 5-1 (Continued)

Criterion	Requirement	Comment
Personnel safety regarding radiation and radioactive materials	Compliance	Sealed massive metal module
Radioactive material restrictions and administrative controls	Compatible	Min volume and 100% confinement

6. DESIGN DOCUMENTATION

All pertinent documentation prepared for the pilot plant fuel particle crushing is shown in the documentation tree, Fig. 6-1, and in Appendix D of this report. Background test information, where applicable, is noted in the text of this report or in the calculations, with complete identification given in the reference listing. Future documentation is planned to report test operational plans and results and modifications in design.

Fig. 6-1. Fuel particle crusher documentation tree

7. ACKNOWLEDGMENTS

The authors wish to express their appreciation to J. W. Allen and B. J. Baxter for managerial guidance and to the design drafting group under the direction of R. H. Sturtevant for their efforts.

APPENDIX A

"DESIGN CRITERIA - FUEL PARTICLE CRUSHER,"
GENERAL ATOMIC DOCUMENT NO. DC 520001, MARCH 1, 1976

GENERAL ATOMIC COMPANY

GA 777 (rev 5/74)

DESIGN CRITERIA - FUEL PARTICLE CRUSHER

Doc. No. DC 520001

Issue A

Date 3/1/76

ISSUE SUMMARY

Issue	Date	Prepared by	Approvals		Acceptance	Purpose of Issue/ Sections Changed
			Engineering	DRB	Project	
DD RELEASED A	3/1/76	<i>J.B. Strand</i> J.B. Strand	<i>W. J. [unclear]</i> 2-27-76 <i>[Signature]</i> 2/27/76			Initial Issue

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GENERAL ATOMIC COMPANY

GA 541 (Rev 5/74)

DESIGN CRITERIA - FUEL PARTICLE CRUSHER

Doc. No. DC 520001

Issue A

Date 3/1/76

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By *James F. Strand*

Approved

Approved

[Signature] 2/27/76

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GENERAL ATOMIC COMPANY

GA 541 (Rev 5/74)

DESIGN CRITERIA - FUEL PARTICLE CRUSHER

Doc. No. DC 520001

Issue A

Date 3/1/76

1.0 SCOPE

This design criteria applies to the fissile and fertile particle crusher of the HTGR Fuel Reprocessing Cold Pilot Plant.

2.0 PERFORMANCE REQUIREMENTS

The fissile and fertile particle crusher shall be designed to remove the silicon carbide TRISO coating from the Fort Saint Vrain type fertile and fissile, and LHTGR fissile fuel particles to expose the thorium carbide and uranium carbide and inner carbon coatings for fluid bed combustion.

The crushing shall be accomplished as a semi-continuous operation on 60 kilogram batches at a rate of 30 kilograms per hour. The crusher shall be fed and discharged by gravity flow and shall have the capability to re-start under a fully loaded condition.

The crusher shall be designed for maximum material accountability, minimum material hold-up, minimum particle losses and sealed from material escape under positive internal pressures of up to 5 PSIG at ambient temperatures. A total of 1% unbroken particles is the maximum allowable quantity. Particle breakage efficiency shall be maximized and particle bypass of the crushing shall be minimized. The minimum average size of the crushed material shall be 160 μ m.

The design of the crusher shall be adaptable to remote operations and maintenance, radiation environments and hot cell temperatures of up to 115°F. The design shall comply with the Category III seismic requirements of RDT Standard F9-2T.

The overall height of the crusher between feed and discharge flange faces shall be 18 inches. The feed flange connects to the 2 inch standard flange from the particle crusher feed bunker. The discharge flange connects to the 4 x 4 inch opening at the top of the secondary burner's feed hopper. The design of the crusher must allow inert gas blanketing of the particles by the secondary burner feed hopper gas or by separate purges.

3.0 SAFETY AND HEALTH REQUIREMENTS

The particle crusher and its associated equipment shall have incorporated into their designs adequate measures for eliminating or minimizing the effects of any credible industrial hazard, including the hazards from pyrophoric materials.

The system shall be designed to be compatible with administratively controlled radiation exposure and operating restrictions for use of natural and depleted uranium and thorium compounds.

The system design shall incorporate adequate measures to insure personnel protection from radiation and airborne radioactive materials and to minimize or eliminate personnel exposure to radiation hazards.

By James B. Staud

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4.0 MATERIAL SAFEGUARDS REQUIREMENTS

The particle crusher shall be designed for minimal material hold-up and losses and maximum material accountability.

5.0 INTERFACE REQUIREMENTS

The particle crusher shall be compatible with these interfacing systems:

1. Particle Crusher Feed Bunker
DC-520101
Dwg. No. 5223009
2. Secondary Burner Feed Hopper
DC-524701
Dwg. No. L002051
3. Plant electrical and gas services
4. Remote maintenance

By James P. Stroud

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APPENDIX B

"FUEL PARTICLE CRUSHER - DESIGN SPECIFICATION,"
GENERAL ATOMIC UNNUMBERED DOCUMENT, APRIL 1975

APPENDIX B
FUEL PARTICLE CRUSHER - DESIGN SPECIFICATION(a,d)
APRIL 1975

Roll diameter		4.0 in.
Roll crushing length		4.0 in.
Roll material	(one)	A.I.S.I. 1015-1020
	(one)	A.I.S.I. 4340
Roll heat treat	(one)	Carburize and heat treat Rc 55-60 crushing surface only
	(one)	Flame harden Rc 55-60 crushing surface only
Roll bearings		2.0 I.D. approx
Roll speed		Variable 20 to 60 rpm
Roll gap ^(b)		0.012 to 0.017 in. fertile 0.010 to 0.012 in. fissile
Drive		Single motor
Drive power		3/4 to 1-1/2 hp approx
Throughput ^(b,c)		30 to 50 kg/hr
Maximum temperature ^(c)		115°F
Reliability		Limited to life of rolls on fixed roll centers
		No roll adjustment capability
		Roll module to be removable
Maintainability		Roll module to be remotely removed and replaced
Ventilation		None provided since hoppers are vented
		Inert gas purge to crushed product hopper discharging through filtered vent
		Crusher will be under slight positive pressure (5 psig) ^(c)
Start-under-load ^(c)		Yes
Dimensional envelope		Minimize

APPENDIX B (Continued)

Efficiency ^(b,c)	Maximum of 1% unbroken particles in secondary burner ash
Accountability ^(c)	Maximize with minimal internal cavities, etc.
Health and safety ^(c)	Adequate measures shall be included

(a) Information from design conferences and meetings except where noted.

(b) Rickman, W. S., "Process Guidelines for Fuel Particle Crushing,"
General Atomic Company unpublished data, April 8, 1975.

(c) Appendix B of this report.

(d) Meeting notes: J. Strand, April 29, 1975.

APPENDIX C

"ACTIVITY PLAN - FUEL PARTICLE CRUSHER,"
GENERAL ATOMIC DOCUMENT NO. AP 520001, APRIL 27, 1976

GENERAL ATOMIC COMPANY

GA 777 (Rev 5/74)

ACTIVITY PLAN - FUEL PARTICLE CRUSHER

Doc. No. AP 520001

Issue C

Date 4/14/77

ISSUE SUMMARY

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			Engineering	DRB	Project	
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B	8/10/76	E. J. Cook	8/10/76			Per ECO #00352
C	4/14/77	W.S. Rickman	4/18/77			Per ECO #00440

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GENERAL ATOMIC COMPANY

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ACTIVITY PLAN - FUEL PARTICLE CRUSHER

Project 3225

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Issue C

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GENERAL ATOMIC COMPANY

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ACTIVITY PLAN - FUEL PARTICLE CRUSHER

Doc. No. AP 520001

Issue C

Date 4/14/77

1.0 SCOPE

This document describes the experimental work to be conducted to develop a fuel particle crusher in the HTGR Fuel Reprocessing Cold Pilot Plant. The scope of the work includes tests necessary to demonstrate that fissile and fertile HTGR fuel particle crushers meet the design and operational capabilities required by the Design Criteria - Fuel Particle Crusher, DC 520001. The scope does not include design efforts, equipment installation, pre-operational testing, demonstrations of semi-remote handling equipment or crushing operations undertaken solely to provide feed for the secondary burner.

The fuel particle crushing system consists of the equipment required to fracture the silicon carbide coating of the Fort St. Vrain-type fertile and fissile fuel particles and the LHTGR-type fissile fuel particles to expose the thorium and uranium compounds and the inner carbon coatings for subsequent fluid-bed combustion. Fuel particle crushing is accomplished using a roll crusher. The roll crusher cracks the fuel particles by the contact between the two counter-rotating roll surfaces and the particles which forces the particles through a narrow gap between the rolls. The gap is sized for the particular particle being crushed by inserting rolls of the proper diameter.

2.0 OBJECTIVES

The objectives of this Activity Plan are to demonstrate that both fuel particle crushers meet the design criteria (DC 520001) and to determine their suitability for use in a hot reprocessing facility. These objectives are as follows:

2.1 Fuel Particle Roll Crusher General Experimental Objectives

- 2.1.1 Demonstrate the ability to fracture the silicon carbide TRISO coatings of the Fort St. Vrain-type fertile and fissile fuel particles and the LHTGR-type fissile fuel particles with a minimum mean size on a weight basis of the crushed material of 160 μ m and a maximum of 1% unbroken fuel particles. Minimum mean size (TBD) for fissile particles.
- 2.1.2 Demonstrate a throughput rate of 30 kg of fuel particles per hour.
- 2.1.3 Demonstrate material accountability, minimum material hold-up and minimum particle loss.
- 2.1.4 Demonstrate material flow, feed and discharge concepts.
- 2.1.5 Demonstrate start under load.
- 2.1.6 Demonstrate capability of instrumentation to monitor and control process.
- 2.1.7 Determine and compare the wear rates of various materials.
- 2.1.8 Develop wear rate acceptance criteria.

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ACTIVITY PLAN - FUEL PARTICLE CRUSHER

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3.0 TEST DESCRIPTION

3.1 General

The design criteria (DC 520001) defines the objectives for the fuel particle roll crusher. The test program is devised to provide data and observations which will demonstrate that the design objectives have been met. The crushers will also be operated solely to provide feed materials for the secondary burner. (See Secondary Burner Activity Plan - AP 524301) and data from these uncontrolled operations will be obtained in significant areas.

3.2 Test Determinations

To establish that the design objectives have been met, the Activity Plan includes the following determinations, comparisons and demonstrations to be made during applicable phases of testing on the roll crusher:

- a) Determination of roll gap settings.
- b) Determination of the throughput rates.
- c) Determination of the crushed product characteristics.
- d) Determination of material accountability, material hold-up and particle losses.
- e) Determination of material flow, feed and discharge concepts.
- f) Demonstration of start under load.
- g) Demonstration of control and instrumentation.
- h) Determination of wear rates.
- i) Comparison of wear rates with different fuel particles.
- j) Comparison of wear rates of different materials of construction.
- k) Comparison of crushing behavior of different types of fuel particles.

3.3 Test Measurements

To provide quantitative and qualitative data which establishes the test determinations of Section 3.2, the following measurements and observations will be obtained from the tests:

- a) Percent unbroken particles.
- b) Crushed material average sizes.
- c) Material balances.
- d) Process times.
- e) Bearing performance.
- f) Material hold-up.
- g) Particle losses.
- h) Material wear rates.

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3.4 Test Phases

To clearly provide the data required to establish that the design objectives have been met, the Activity Plan for the fuel particle crushers has been divided into three phases.

Replicate identical tests will be performed for each major test objective within the test phases. Random experimental errors have equal probability of being high or low and this precludes the use of a single test. If two tests are performed, the more precise one cannot be determined. Therefore, the average of three experimental values will be more precise than one or two. To increase this precision, additional replicate tests can be made. However, to provide similar precision for each major test objective, any additional replicate tests performed on one should be performed on all. This results in fifteen tests for each replicate added and necessitates restricting the quantity to three per major test objective as a viable compromise between precision and cost/schedule considerations.

The three phases are defined as follows, the testing is outlined in Table I, and performance of the tests is described in the Operating Procedures (OP 520001).

Phase I - Demonstration of roll crusher with Fort St. Vrain-type fertile fuel particles.

Phase II - Demonstration of roll crusher with Fort St. Vrain-type fissile fuel particles.

Phase III - Demonstration of roll crusher with LHTGR-type fissile fuel particles.

3.4.1 Phase I - Demonstration of the Roll Crusher with Fort St. Vrain-Type Fertile Fuel Particles

The major objective of Phase I of the Activity Plan is to demonstrate that the roll crusher's design and operational capabilities meet the requirements of the design criteria (DC 520001) while breaking Fort St. Vrain-type fertile fuel particles.

Testing includes applicable demonstrations, determinations, and comparisons listed in Section 3.2 and applicable measurements and observations listed in Section 3.3

Because of the handling difficulties and the cost of the fuel particles, the tests will be conducted using the smallest practical quantity of fuel particles. Normal crushing operations conducted to provide feed for the secondary burner will be utilized to obtain wear data. Pre-operational tests will be performed to determine the proper gap for crushing.

The testing consists of experiments outlined in Table I, attached.

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3.4.2 Phase II - Demonstration of the Roll Crusher with Fort St. Vrain-Type Fissile Fuel Particles

The major objective of Phase II of the Activity Plan is to demonstrate that the roll crusher's design and operational capabilities meet the requirements of the design criteria (DC 520001) while breaking Fort St. Vrain-type fissile fuel particles and is conducted as outlined in Section 3.4.1 for fertile particles.

The testing consists of experiments outlined in Table I, attached.

3.4.3 Phase III - Demonstration of the Roll Crusher with LHTGR-Type Fissile Fuel Particles

The major objectives of Phase III of the Activity Plan is to demonstrate that the roll crusher's design and operational capabilities meet the requirements of the design criteria (DC 520001) while breaking LHTGR-type fissile fuel particles and is conducted as outlined in Section 3.4.1 for FSV fertile particles.

Testing consists of experiments outlined in Table I, attached.

4.0 ACCEPTANCE CRITERIA

The degree of success of each phase of the Activity Plan is based upon meeting the requirements of the design criteria (DC 520001).

Acceptance criteria are based on demonstrations of performance and quantified data which prove that the requirements of the design criteria have been met. Quantified acceptance criteria are as follows:

4.1 Acceptance Criteria - Phase I - Demonstration of Roll Crusher with Fort St. Vrain-Type Fertile Fuel Particles

Throughput rate - ≥ 30 kg per hour.

Crushed product - $< 1\%$ unbroken particles with a mean size on a weight basis of $\geq 160 \mu\text{m}$.

Material accountability - $\leq 0.5\%$ of throughput unaccounted .

Start-up - fully loaded.

Dust confinement - 100% within roll enclosure.

4.2 Acceptance Criteria - Phase II - Demonstration of Roll Crusher with Fort St. Vrain-Type Fissile Fuel Particles

Acceptance criteria are the same as shown in Section 4.1 for Phase I except:

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Crushed material product - $\leq 1\%$ unbroken particles with a mean size to be determined.

4.3 Acceptance Criteria - Phase III - Demonstration of Roll Crusher with LHTGR-Type Fissile Fuel Particles

Crushed material product - $\leq 1\%$ unbroken particles with a mean size to be determined.

5.0 SAFETY REQUIREMENTS

The operation of the roll crusher shall be conducted in a manner which ensures that the following safety requirements are met:

- a) Their use is restricted to natural or depleted uranium and thorium compounds.
- b) Power switches shall be locked out during all repairs, adjustments, and hands-on operations.
- c) The requirements of the Occupational Safety and Health Act (OSHA) shall be strictly enforced.
- d) Radiological safety and handling procedures shall be strictly enforced.
- d) Dismantling, maintenance or adjustments which potentially expose pyrophoric materials will be done only in accordance with written procedures.

6.0 QUALITY ASSURANCE REQUIREMENTS

Documentation as described in the Design Document Index - Fuel Particle Crushing, DI 520001, shall be provided. In addition, calculations, test procedures, test reports, instrument calibration reports and failure reports will be prepared. An objective of the Activity Plan is the development of equipment operating procedures applicable to HRDF and the determination of requirements for operator qualification and requalification. All Quality Assurance activities will be conducted in accordance with the Quality Assurance Program Document for the Thorium Utilization Program, QAPD-3225.

7.0 SCHEDULE

The experimental work described in Section 3.0 shall be conducted according to the schedule shown on Table II, attached.

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Table 1 - Fuel Particle Crusher Testing

<u>Phase</u>	<u>Equipment</u>	<u># Tests</u>	<u>Feed Mat'ls. - Each Test</u>	<u>Major Test Objective</u>
I	Roll Crusher	T.B.D.	$\leq$ 0.5 kg FSV fertile fuel particles	Det. proper roll gap setting WRT crushed prod. charac.
I	Roll Crusher	3	$\leq$ 1.5 kg FSV fertile fuel particles	Det. crushed prod. charac. WRT throughput rates.
I	Roll Crusher	1	$\leq$ 0.5 kg FSV fertile fuel particles	Demon. start under load.
II	Roll Crusher	T.B.D.	$\leq$ 0.5 kg FSV fissile fuel particles	Det. proper roll gap setting WRT crushed prod. charac.
II	Roll Crusher	1	$\leq$ 0.5 kg FSV fissile fuel particles	Det. crushed prod. charac.
III	Roll Crusher	T.B.D.	$\leq$ 0.5 kg LHTGR fissile fuel particles	Det. roll gap settings WRT crushed prod. charac.
III	Roll Crusher	1	$\leq$ 0.5 kg LHTGR fissile fuel particles	Det. crushed prod. charac.

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TABLE II

EXPERIMENTAL SCHEDULE - FUEL PARTICLE CRUSHING

CALENDAR YEAR 1976				CALENDAR YEAR 1977				CALENDAR YEAR 1978									
TRANS QUARTER		FISCAL YEAR 1977				FISCAL YEAR 1978											
MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT

PHASE I 11 KG FSV FERTILE

PHASE II 11 KG FSV FISSILE

PHASE III 11 KG LNTGR FISSILE

Notes: 1) Table does not include time to completion of wear studies via burner feed preparation.

2) Table does not include burner feed requirements.

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APPENDIX D

"DESIGN DOCUMENT INDEX: FUEL PARTICLE CRUSHING,"
GENERAL ATOMIC DOCUMENT NO. DI-520001, OCTOBER 18, 1974

GENERAL ATOMIC COMPANY

GA 777 (Rev 5/74)

DESIGN DOCUMENT INDEX: FUEL PARTICLE CRUSHING

Proj. No. 3225

Doc. No. DI 520001

Issue C

Date 6/7/76

ISSUE SUMMARY

Approval Level: 3

Issue	Date	Prepared by	Approvals		Acceptance	Purpose of Issue/ Sections Changed
			Engineering	DRB	Project	
A	10/18/74	B. Baxter				Initial Issue
B	SEP 04 1975	J. S. Rode <i>J.S. Rode</i>	<i>Cor. Head</i>			General Revision/ Sections 1.2, 1.3, and 2.0
	6/7/76	J. B. Strand <i>J.B. Strand</i>	<i>J. B. Strand</i> <i>Cor. Head</i> <i>6/11/76</i>			Release basis: DI500001 Issue A Revision per ECO #00243

1 RELEASED
SEP 04 1975DD RELEASED
6/11/76

Do not write in space below. Continue Issue Summary on GA Form 778.

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1.0	GENERAL DESCRIPTION	4
1.1	Function	4
1.2	Design Basis	4
1.3	Interfaces	4
2.0	DESIGN DOCUMENT LIST	4,5

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B. Baxter

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1.0 GENERAL DESCRIPTION

1.1 Function

The fuel particle crushing system provides the means by which SiC coatings can be removed from TRISO fuel (Fort St. Vrain type), thereby exposing the fuel kernels.

1.2 Design Basis

The fuel particle crushing system is designed to remove SiC coatings from fuel kernels.

The crushing system for processing fertile particles utilizes a pair of rollers - between which the coated particles are passed.

The crushing system for processing fissile particles utilizes either a double-roll crusher or a pneumatic jet stream which entrains the particles and impacts them against an impingement plate.

The crushing system is designed to provide a feed having a maximum of one percent unbroken fuel particles to the secondary (20-cm) fluidized-bed burner.

1.3 Interfaces

The fuel particle crushing system for fertile particles requires electrical service, an off-gas or ventilation system for dust control, and a drive system.

The fuel particle crushing system for fissile particles requires a gas supply to the jet and an off-gas or ventilation system.

The system must interface with the solids handling system and the secondary (20-cm) fluidized-bed burner system.

2.0 DESIGN DOCUMENT LIST

The following list describes those documents, specifications and drawings which are pertinent to the crushing systems for both fertile and fissile particles.

By J. S. Rode/
B. J. Baxter

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PROJECT 3225

DDI TITLE: FUEL PARTICLE CRUSHING

DDI NO. 520001 ISSUE C

PAGE 4 OF 4 DATE .

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APPENDIX E
DESIGN CALCULATIONS

- E.1 Particle Fracture Stress
- E.2 Particle Fracture Loads
- E.3 Particle Distribution
- E.4 Total Crushing Forces
- E.5 Crusher Throughput
- E.6 Power Requirements
- E.7 3" Experimental Crusher
- E.8 Crusher Drive
- E.9 Gear Design
- E.10 Roll Design

REFERENCES

- E-1. Brecker, J. N., "The Fracture Strength of Abrasive Grains," Trans. ASME, Ser. B, J. Eng. Ind. 96, 4 (1974), p. 1253.
- E-2. DeLesdernier, D., "Pneumatic Classification of Fort St. Vrain Fuel Particles," General Atomic Company Report GA-A13135, June 1975.
- E-3. Rickman, W. S., "ACC Development Data Request, ACC-GAC-4," General Atomic Company unpublished data, January 30, 1975.
- E-4. "Electrical and Mechanical Drive Products," Reliance Electric Co., Catalog A-108, 1975-1976.
- E-5. "Stock Spur Gears," Ohio Gear Co., Catalog No. 640RR.
- E-6. Bradford, L. J. and P. B. Eaton, Machine Design, John Wiley & Sons, Inc., New York, 1940.
- E-7. Timoshenko, S. and G. MacCullough, Elements of Strength of Materials, D. Van Nostrand Co., Inc., New York, 1940.

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CALCULATIONS FOR PARTICLE FRACTURE STRESSES - ROLL DESIGN			
EQUIP NO	PROJ NO	CALC NO E-1	PAGE 1 OF 38
PREPARED BY	DATE	REF DOCUMENTS J.N. BRECKER, 'THE FRACTURE STRENGTH OF ABRASIVE GRAINS', ASME JOURNAL OF ENGINEERING FOR INDUSTRY, NOV 1974 P1253-1257 REF E-1	
REVIEWED BY	DATE		
APPROVED BY	DATE		

DETERMINE RELATIVE RELATIONSHIP TO PARTICLE SIZE AND PARTICLE STRENGTH WHILE ROLL CRUSHING REGULAR Al_2O_3 AND BLACK SiC , FROM BRECKER P. 1255 AND P. 1256 AND FIGURE 5. (#12 GRAIN IS .060 IN DIA)

FRACTURE STRESS AT .022 IS:

$$\frac{16.5}{26.0} = \frac{X}{50}$$

$$X = 31,731 \text{ psi}$$

CALCULATE SLOPE OF SiC LINE:

$$\frac{31,730 - 16,500}{.060 - .022} = \frac{401 \text{ psi}}{.001 \text{ IN CHANGE IN DIAMETER}}$$

FRACTURE STRESS σ AT 0.0185" IS:

$$\begin{aligned} \sigma_{.0185} &= (.022 - .0185) \times 401 \text{ psi} / .001 \text{ in} + 31,730 \text{ psi} \\ &= 33,130 \text{ psi} \end{aligned}$$

$$\begin{aligned} \sigma_{.0311} &= (.060 - .0311) \times 401 / .001 \text{ in} + 16,500 \text{ psi} \\ &= 28,093 \text{ psi} \end{aligned}$$

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CALCULATIONS FOR PARTICLE FRACTURE LOAD, BTC - ROLL DESIGN

EQUIP. NO.	PROJ. NO.	CALC. NO. E-2	PAGE 2 OF
PREPARED BY	DATE	REF. DOCUMENTS: ① D. DELESNERIE, "PNEUMATIC CLASSIFICATION OF FSU FUEL PARTICLES" GA-A 13135, FEB, E-2	
REVIEWED BY	DATE	③ RDB-WSR-164-75 PROCESS GUIDELINES FOR FUEL PARTICLE CRUSHING" 1975, REF 4-3	
APPROVED BY	DATE		

PARTICLE SIZE DISTRIBUTION FOR FERTILE PARTICLES FROM DELESNERIE P 4-7, FIG 4-5, FERTILE "B" DATA:

PARTICLE SIZE. μ	② Q-IN. (DIA)	FRACTURE STRESS ⑥ σ_c - PSI	FRACTURE LOAD ⑧ P - LBS	NIP ANGLE ④ α - DEGREES
470	.0185	33,130	7.6	3.26
490	.0193	33,810	8.2	3.45
510	.0201	32,490	8.8	3.64
530	.0209	32,171	9.4	3.81
550	.0217	31,851	10.0	3.98
570	.0224	31,571	10.6	4.12
590	.0232	31,251	11.3	4.28
610	.0240	30,931	12.0	4.43
630	.0248	30,611	12.6	4.57
650	.0256	30,291	13.3	4.71
670	.0264	29,972	14.0	4.85
690	.0272	29,652	14.7	4.98
710	.0280	29,332	15.4	5.11
730	.0288	29,052	16.1	5.22
750	.0295	28,732	16.8	5.34
770	.0303	28,412	17.5	5.46
790	.0311	28,093	18.2	5.58

- NOTES:
- ② MIDPOINT OF STEPPED DATA PLOT, FIG 4-5. (FERTILE)
 - ⑥ SEE CALC E-1. REF E-1
 - ⑧ $P = \sigma_c a^2 \div 1.49$: BREECKER, p 1254, SPHERICAL PARTICLES
 - ④ $\alpha = \arccos [(2R+g)/2R+2r]$ FOR 4" ROLLS
 $2R$ = DIAMETER OF CRUSHING ROLL
 $2r$ = DIAMETER OF PARTICLES = Q IN INCHES
 g = MINIMUM ROLL GAP = .012 INCHES PER
RDB WSR 164-75 - REF 4-3

AVERAGE PARTICLE SIZE IS 630 μ = .010248 INCHES

PART FRACT LOADS E-2

CALCULATIONS FOR PARTICLE DISTRIBUTION IN CAVITY - Row DESIGN			
EQUIP. NO.		PROJ. NO.	CALC. NO. E-3
PAGE 3 OF			
PREPARED BY		DATE	REF. DOCUMENTS:
REVIEWED BY		DATE	
APPROVED BY		DATE	

DISTRIBUTION OF PARTICLES ON ROLL FACE :

$$R \sin \alpha = Y$$

$$Y_2 - Y_1 = Y_3 = \text{VERTICAL DISTRIBUTION}$$

$R = \text{RADIUS OF CRUSHING ROLL}$
 $= 2 \text{ INCHES}$

$$\alpha = \text{NIP ANGLE MAX \& MIN}$$

$$y_1 = 2 \sin 3.26^\circ = 0.1137$$

$$y_7 = 2 \sin 5.58^\circ = .1945$$

$$Y_3 = 0,080\text{g}$$

VERTICAL DISTRIBUTION WITH AVERAGE SIZE PARTICLE:

AVERAGE PARTICLE

SINGLE ROW SPACING (S)

$$S = 2r \sin 60^\circ$$

$R_T = 'a'$

Assume Average $a = 0.0208 \text{ in.}$

$S = 0.02148'' / \text{ROW OF AVG PARTICLES}$

NUMBER OF ROWS IN $Y_3 = \frac{0.0808}{0.0248} = 3.76$ ROWS

NUMBER OF AVERAGE PARTICLES ACROSS: ROLL TRACK WIDTH:

$$1.0'' \div .0248'' = \underline{\underline{40 \text{ PARTICLES / INCH OF ROLL WIDTH}}}$$

TOTAL PARTICLES (AUG) IN CRUSHING ZONE

$$40/\text{IN} \times 3.76 \text{ Rows} = \underline{\underline{150 \text{ PARTS PER INCH ROLL WIDTH}}}$$

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CALCULATIONS FOR TOTAL CRUSHING FORCES - ROLL DESIGN			
EQUIP. NO.	PROJ. NO.	CALC. NO. E-4	PAGE 4 OF
PREPARED BY	DATE	REF. DOCUMENTS:	
REVIEWED BY	DATE		
APPROVED BY	DATE		

TOTAL CRUSHING FORCE = SEPARATING FORCE

$$F_{CP} = \frac{\text{No. AVG PARTICLES}}{\text{INCH OF WIDTH}} \times \text{FRACTURE LOAD / AVG PARTICLE}$$

$$= 150 \times 12.6 \text{ LBS/pc} = 1890 \text{ LBS / INCH OF ROLL WIDTH}$$

$$\underline{F_{CP}} = 1890 \times 4 \text{ IN} = \underline{7560 \text{ LB}} \text{ WITH CLOSE PACKED PARTICLES}$$

ASSUME ONLY SINGLE ROW CRUSHING:

$$F = \text{NO OF PARTICLES ACROSS ROLL WIDTH} \times \text{FRACTURE LOAD}$$

AVERAGE PARTICLE (.0248 DIA)

$$F_{AVG} = \frac{4.0 \text{ IN}}{.0248 \text{ IN}} \times 12.6 \text{ LB/pc} = \underline{2032 \text{ LB}}$$

MAXIMUM PARTICLE

$$F_{MAX} = \frac{4.0 \text{ IN}}{.0311 \text{ IN}} \times 18.2 \text{ LB/pc} = \underline{2341 \text{ LB}}$$

MINIMUM PARTICLE

$$F_{MIN} = \frac{4.0}{0.185} \times 7.6 \text{ LB/pc} = \underline{1643 \text{ LB}}$$

TOTAL CRUSH FORCE E-4

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CALCULATIONS FOR CRUSHER THROUGHPUT VERIFICATION			
EQUIP. NO.	PROJ. NO.	CALC. NO. E-5	PAGE 5 OF 38
PREPARED BY	DATE	REF. DOCUMENTS: W.S. RICKMAN MEMO "ACC DEVELOPMENT DATA REQUEST # ACC-GAC-4" RDB-WSR-62-75 1/30/75 RAC E-3	
REVIEWED BY	DATE		
APPROVED BY	DATE		

THRUPTUT FOR 4x4 ROLL CRUSHER WILL BE VERIFIED BASED UPON THE MEASURED THRUPTUT AND APPARENT PARTICLE DENSITY RESULTING FROM THIS THRUPTUT OF THE 3x1 EXPERIMENTAL CRUSHER

$$\text{THRUPTUT} = V_T = \frac{\text{VOL}}{\text{UNIT OF TIME}} \times \text{SPEED} \times \text{PARTICLE DENSITY}$$

$$\text{VOL} = \text{GAP AREA} \times \text{ROLL CIRCUMF}$$

$$V_T = g \times w \times \pi D \times \text{r.p.m.} \times \rho$$

WHERE FROM RDB-WSR-62-75:

$$D = 3.0 \text{ INCH}$$

$$g \approx .017 \text{ INCH}$$

$$w = 1.0 \text{ INCH}$$

$$\text{r.p.m.} = 29$$

$$V_T \approx 10 \text{ Kg/HR}$$

CALCULATE FOR APPARENT PARTICLE DENSITY ρ :

$$\rho = \frac{10 \text{ Kg/HR}}{.017 \text{ IN} \times 1.0 \text{ IN} \times \pi \times 3.0 \text{ IN} \times 29 \text{ rpm} \times 60} = \frac{10 \text{ Kg}}{279 \text{ IN}^3}$$

$$= \underline{\underline{2.18 \text{ gm/cc}}}$$

CALCULATE FOR THRUPTUT OF 4x4 CRUSHER USING ρ :

$$V_T = .012 \times 4.0 \times \pi \times 4.0 \times \text{rpm} \times 60 \times \rho \times \frac{1}{6.10 \times 10^{-2} \text{ IN}^3/\text{CC}}$$

$$V_{T30} = 38.8 \text{ Kg/HR}$$

$$V_{T60} = 77.6 \text{ Kg/HR}$$

$$V_{T40} = 51.7 \text{ Kg/HR}$$

THUS A CRUSHER WITH 4 IN. DIA X 4 IN. WIDE ROLLS OPERATING AT 240 RPM WILL MEET THE DESIGN REQMT OF 50 Kg/HR.

CALCULATIONS FOR POWER REQUIREMENTS FOR CRUSHER DRIVE			
EQUIP NO	PROJ. NO.	CALC NO. E-6	PAGE 6 OF
PREPARED BY	DATE	REF DOCUMENTS	
REVIEWED BY	DATE		
APPROVED BY	DATE		

DETERMINE H.P. RESULTS WITH F_{MAX} , F_{MIN} , F_{AUG} , $F_{MAX CP}$:

[NEGLECT NIP ANGLE α AND
LOAD VECTORS AT TANGENCY.]

$$HP = \frac{2\pi N T}{33000 \times 12}$$

$$= 15.9 \times 10^{-6} NT$$

N = SPEED OF ROLLS (RPM)

T = TORQUE RESULTING FROM
SEPARATING FORCE ACTING
AT DISTANCE y .

$$= F \times y \quad (IN-LB)$$

HP WITH CLOSE PACKED PARTICLES:

$$HP = 15.9 \times 10^{-6} \times N \times F_{MAX CP} \times Y_2$$

$$N = 30 \text{ RPM} \text{ \& } 60 \text{ RPM}$$

$$F_{C.P.} = 7560 \text{ LB} \quad (\text{CALC E-4})$$

$$Y_1 = Y_1 + \frac{Y_3}{2} = 0.1541 \text{ IN.} \quad (\text{CALC E-3})$$

$$HP_{30} = 15.9 \times 10^{-6} \times 30 \times 7560 \times 0.1541 = \underline{0.55} / \text{ROLL}$$

$$HP_{60} = 15.9 \times 10^{-6} \times 60 \times 7560 \times 0.1541 = \underline{1.10} / \text{ROLL}$$

HP WITH SINGLE ROW MAX PARTICLE SIZE

$$F_{MAX} = 2341 \text{ LB} \quad (\text{CALC E-4})$$

$$Y_2 = 0.1945 \text{ IN} \quad (\text{CALC E-3})$$

$$HP_{30} = \underline{.22}$$

$$HP_{60} = \underline{.44}$$

POWER FRONT **E-6**

CALCULATIONS FOR <u>POWER REQUIREMENTS - HP CALCULATIONS</u>			
EQUIP. NO.	PROJ. NO.	CALC. NO. <u>E-6</u>	PAGE <u>7</u> OF
PREPARED BY	DATE	REF. DOCUMENTS:	
REVIEWED BY	DATE		
APPROVED BY	DATE		

HP FOR SINGLE ROW MINIMUM PARTICLE SIZE

$$HP = 15.9 \times 10^{-6} \times N \times F \times Y$$

$$N = 30 \text{ \& } 60 \text{ RPM}$$

$$F_{min} = 1643 \text{ LB} \quad (\text{CALC E-4})$$

$$Y_1 = .1137 \text{ IN} \quad (\text{CALC E-3})$$

$$HP_{30} = \underline{.09}$$

$$HP_{60} = \underline{.18}$$

HP FOR SINGLE ROW AVERAGE PARTICLE SIZE

$$N = 30 \text{ \& } 60 \text{ RPM}$$

$$F_{avg} = 2032 \text{ LB} \quad (\text{CALC E-4})$$

$$Y = Y_1 + \frac{Y_2}{2} = 0.1541 \text{ IN} \quad (\text{CALC E-3})$$

$$HP_{30} = \underline{.15}$$

$$HP_{60} = \underline{.30}$$

HP REQUIRED FOR SINGLE MOTOR DRIVING BOTH ROLLS WILL BE DOUBLE THE VALUES SHOWN WHICH ARE THE RESULTS FOR EACH ROLL.

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CALCULATIONS FOR Power Requirements - HP Summary

EQUIP. NO.	PROJ. NO.	CALC. NO. <u>E-6</u>	PAGE <u>8</u> OF
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SUMMARY OF HP REQUIREMENTS UNDER
VARIOUS LOADING CONDITIONS AND SPEEDS

LOAD- SPEED - RPM	HORSEPOWER			
	7560-C.P.	2341-MX	2032-AVG	1643-MIN
30	1.10	0.44	0.30	0.18
60	2.20	0.88	0.60	0.36
43 (OPERATIONAL)	1.60	0.63	0.43	0.26

Cp: close packed

MX: MAX PARTICLE SIZE (single row)

MIN: MIN " " " "

AVG = AVG " " " "

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CALCULATIONS FOR POWER REQUIREMENTS - EXPERIMENTAL 3" CRUSHER			
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RECALCULATE USING 3 INCH DIA ROLL WITH 1 INCH WIDE FACE IN PLACE OF 4 INCH ROLL WITH 1 INCH FACE WHERE:

$R = 1.5 \text{ INCHES}$
 $g = .012 \text{ INCHES}$
 $2r = \alpha = \text{PARTICLE DIA. INCHES}$
 $\alpha = \text{NIP ANGLE}$
 $Y = \text{LOAD POSITION}$

NIP ANGLES

$\alpha = \text{Arc cos} \left[\frac{2R+g}{2R+2r} \right] \quad (\text{CALC. E-2})$
 WITH ~~2r~~ $2r = 0.0185 \quad (\text{CALC. E-2})$
 $\alpha_{\min} = \underline{3.76^\circ}$
 WITH ~~2r~~ $2r = 0.0311 \quad (\text{CALC. E-2})$
 $\alpha_{\max} = \underline{6.43^\circ}$

DISTRIBUTION OF PARTICLES IN CRUSHING CAVITY

$Y = R \sin \alpha \quad R = 1.5 \text{ INCHES} \quad (\text{CALC. E-3})$
 $Y_1 = 0.0984 \text{ (MIN)}$
 $Y_2 = 0.1679 \text{ (MAX)}$
 $Y_3 = 0.0695 \text{ (SPREAD)}$
 $Y_4 = Y_1 + \frac{Y_3}{2} = 0.1331 \text{ (TO MIDPOINT)}$

3" EXPERIMENTAL E-7

CALCULATIONS FOR <u>POWER REQUIREMENTS - EXPERIMENTAL 3" CRUSHER</u>			
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VERTICAL DISTRIBUTION

USING CLOSE PACKED VERTICAL DISTRIBUTION
AS WITH 4" CRUSHER (CALC-E-3) & AVERAGE PARTICLES,

$$\text{NUMBER OF VERTICAL ROWS} = \frac{.0695 \text{ INCH}}{.02148 \text{ INCH/ROW}}$$

$$= \underline{\underline{3.24 \text{ ROWS AVG PARTICLES}}}$$

TOTAL N = PARTICLES IN CRUSHING ZONE - AVG PARTICLES

$$\frac{1.0 \text{ INCH WIDE}}{0.0248 \text{ INCH DIA}} \times 3.24 \text{ ROWS} = \underline{\underline{130 \text{ PARTICLES/INCH}}}$$

CRUSHING LOADS IN 3" CRUSHER

$$F = N \text{ PARTICLES/INCH} \times \text{WIDTH} \times \text{FRACTURE LOAD/PARTICLE}$$

CLOSE PACKED AVG PARTICLES

$$F = 130 \times 1 \times 12.6 = \underline{\underline{1638 \text{ LBS}}}$$

SINGLE ROW PARTICLES

$$F = \text{PARTICLES/INCH} \times \text{FRACTURE LOAD}$$

$$F_{\text{MIN}} = \frac{1.0 \text{ INCH}}{.0185 \text{ INCH DIA}} \times 7.6 \frac{\text{LB}}{\text{PART}} = \underline{\underline{411 \text{ LB}}}$$

$$F_{\text{MAX}} = \frac{1.0}{.0311} \times 18.2 = \underline{\underline{585 \text{ LB}}}$$

$$F_{\text{AVG}} = \frac{1.0}{.0248} \times 12.6 = \underline{\underline{508 \text{ LB}}}$$

GENERAL ATOMIC COMPANY

CALCULATIONS FOR POWER REQUIREMENTS - EXPER. 3" CEUSITER			
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HP REQUIREMENTS UNDER WORST CONDITION

$$HP = \frac{2\pi INT}{33000 \times 12}$$

WHERE $N = 29 \text{ RPM PER RDB WSR-164-75}$ REF 4-3
 $T = F \times Y \text{ IN WORST CONDITION}$

$$HP = \frac{2\pi \times 29 \times 1638 \text{ LB} \times 0.1331 \text{ IN}}{33000 \times 12 \text{ "/ft}}$$

$$= 0.0995 \text{ PER ROLL}$$

SINCE A SINGLE MOTOR DRIVES BOTH ROLLS
 TOTAL HP IS $2 \times 0.0995 \text{ HP}$

$$\underline{HP = 0.20}$$

DETERMINE HP REQ'D WITH $F_{MAX} = 585 \text{ LB}$ ^{CALC} (E-7, P.10)

$$HP = \frac{2\pi INT}{33000} \quad N = 29 \text{ RPM} \quad Y = .1331 \text{ (E7, P.9)} \quad \text{CALC}$$

$$T = F \times Y$$

$$HP = \frac{2\pi \times 29 \times 585 \text{ LB} \times .1331 \text{ "}}{33000 \times 12 \text{ "/ft}} = .036 \text{ PER ROLL}$$

$$HP_{\text{TOTALS}} = \underline{\underline{.072}}$$

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CALCULATIONS FOR POWER REQUIREMENTS - EXPERIMENTAL 3" CRUSHER			
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THE RUNNING LOAD WITH A FULL CAVITY OF PARTICLES WAS CHECKED WITH AN AMMETER FOR THE 3 IN. EXPERIMENTAL CRUSHER. IT WAS FOUND THAT THERE WAS NO RECORDABLE DEMAND USING A $\frac{1}{2}$ HP MOTOR AT 29 RPM, UNDER FULL LOAD CONDITIONS. MORE VARIATION IN CURRENT DEMAND WAS NOTED FROM A COLD START TO OPERATING TEMPERATURE OF THE MOTOR/REDUCER/GEAR TRAIN ARRANGEMENT. (UNPUBLISHED DATA)

SCALE UP FOR PILOT PLANT CRUSHER ASSUMING 60 RPM ROLL SPEED, 4 INCH WIDE ROLLS:

HP REQ'D UNDER WORST LOADING (E-7, p 11)

$$0.2 \times \frac{60}{29} \times \frac{4}{1} \times \frac{.1541}{.1331} \quad \text{WHERE } \frac{60}{29} \text{ IS ROLL SPD RATIO,}$$

$\frac{4}{1}$ IS FACE WIDTH RATIO

$\frac{.1541}{.1331}$ IS CORRECTION FOR Y

$$HP_{\text{worst}} = \underline{1.92}$$

HP UNDER F_{max} CONDITIONS (ABOVE)

$$0.072 \times \frac{60}{29} \times \frac{4}{1} \times \frac{.1541}{.1331}$$

$$HP_{\text{Fmax}} = \underline{0.69}$$

CALCULATIONS FOR <u>PARTICLE CRUSHER DRIVE - COLD PILOT PLANT</u>			
EQUIP. NO.	PROJ. NO.	CALC. NO. <u>E-8</u>	PAGE <u>13</u> OF
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CONSIDER TWO BASIC ARRANGEMENTS:

1. DIRECT DRIVE THROUGH SHAFT OF ONE ROLL GEAR
2. DRIVE THROUGH DRIVE PINION TO ONE ROLL GEAR

TORQUE REQUIREMENTS ARE BASED ON LOAD CALCULATIONS FROM ^{CALC} E-4, p 4 USING A CRUSHING LOAD OF 7560 LBS FOR CLOSE PACKED PARTICLES AND 2341 LBS FOR SINGLE ROW MAX. SIZED PARTICLES:

$$F_{c.p} = 7560 \text{ LB}$$

$$F_{MAX} = 2341 \text{ LB}$$

CALCULATIONS FOR PARTICLE CRUSHER DRIVE - DIRECT DRIVE			
EQUIP NO	PROJ NO	CALC NO E-8	PAGE 1A OF
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DIRECT DRIVE CALCULATIONS FOR REDUCER

OUTPUT, MOTOR HORSEPOWER & GEAR TOOTH LOAD

ASSUME ROLL GEARS HAVE APPROX 4.0 INCH

DIAM DIAMETERS EQUAL TO ROLL DIAMETERS.

REDUCER TORQUE OUTPUT

EACH GEAR & ROLL CONSUMES EQUAL POWER &

CRUSHING, EQUAL TO CRUSHING LOAD TIMES

CRUSHING DISTANCE (SEE CALL E6, p6 & E-4)

$$\underline{\text{TORQUE}}_{\text{(OUT)}} = 7560 \text{ LB} \cdot \text{IN} \times 2 \text{ ROLLS}$$

$$= \underline{2330 \text{ IN LB}}$$

TOOTH LOAD PER GEAR EQUALS OVERHUNG LOAD (OHL)
ON REDUCER.

$$T_L = 7560 \cdot .1541 \cdot \frac{1 \text{ GEAR}}{2.0 \text{ IN. RADIUS}}$$

$$= 1165 \text{ IN LB} / 2.0 \text{ IN.}$$

$$= \underline{582 \text{ LB}}$$

OUTPUT SPEED EQUALS ROLL SPEEDS — 2076 RPM

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CALCULATIONS FOR PARTICLE CRUSHER DRIVE - DIRECT DRIVE			
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REVIEWED BY	DATE		
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USE P D 29 & SELECT SPEED REDUCER WITH DESIRED TORQUE AND OVERHUNG LOAD CAPACITY:
 SIZE: 180 G 30
 SPEED OUTPUT = 58 RPM (60 RPM REQ)
 REDUCTION RATIO = 30:1
 MOTOR SPEED = 1750 RPM
 TORQUE OUTPUT = 2443 IN-LB (2330 REQ)
 OVERHUNG LOAD = 2270 LB (582 REQ)
 H.P. REQ'D = 3.0

RECALCULATING USING CRUSHING LOAD OF 2341 LBS:

REDUCER TORQUE OUTPUT

$$= 2341^{\#} \times .1541^{\#} \times 2^{\text{Rows}} = 721 \text{ IN-LB}$$

TOOTH LOAD

$$= 2341^{\#} \times .1541^{\#} \times \frac{1}{2.0} = 180 \text{ LB}$$

USING P D 29 RELIANCE:
 SIZE: 56 E 30
 SPEED OUTPUT = 58 RPM (60 RPM REQ)
 RED. RATIO = 30:1
 MOTOR SPEED = 1750 RPM
 TORQUE OUTPUT = 820 IN-LB (721 REQ'D)
 OVERHUNG LOAD = 1350 LB (180 REQ'D)
 HP REQ'D = 1.0

OPTIONS AT 3/4 H.P.:

SIZE: 56 D 30
 30:1, 596 IN-LB, 970 OHL, 3/4 HP

CALCULATIONS FOR PARTICLE CRUSHER DRIVE - PINION DRIVE

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PINION DRIVE CALCULATIONS:

TORQUE REQUIREMENTS FOR $F = F_{CD}$ (SEE CALC E-6, p 68E4)

REDUCER TORQUE OUTPUT

TORQUE RED. = TORQUE R.H. Pin. + TORQUE L.H. Pin.

$$\text{TORQUE R.H.} = F_{CD} \times .1541 = 7560 \times .1541 = 1165 \text{ IN. LB.}$$

$$\text{TORQUE L.H.} = 1165 \text{ IN. LB.}$$

$$\text{TORQUE REDUCER OUTPUT} = 2 \times 1165 = \underline{2330 \text{ IN. LB.}}$$

TOOTH LOADS AT $F = F_{CD}$

$$TL = \text{TORQUE} / PD \div 2$$

$$TL_{LH} = 1165 / 4 \div 2 = 582 \text{ LB}$$

$$TL_{RH} = 582 \text{ LB (REQUIRED) (SEE BELOW)}$$

$$\text{PINION TOOTH LOAD} = TL_{RH} + TL_{LH} = \underline{1165 \text{ LB}}$$

NOTE: SINCE RH GEAR TRANSMITS DRIVING FORCE FOR BOTH ROLLS FROM PINION, IT WILL EXPERIENCE SAME TOOTH LOAD AS PINION. E-1

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CALCULATIONS FOR

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REDUCER OUTPUT TORQUE IS TOOTH LOAD
TIMES PITCH RADIUS OF PINION:

$$\begin{aligned} \text{TORQUE OUT AT 4 P.D.} &= 1165'' \times 2.0' \\ &= \underline{2330 \text{ IN-LB}} \end{aligned}$$

$$\begin{aligned} \text{TORQUE OUT AT 6 PD} &= 1165 \times 3.0 \\ &= \underline{3495 \text{ IN-LB}} \end{aligned}$$

DETERMINE REDUCER REDUCTION RATIO FOR EACH
DRIVE PINION PITCH DIAMETER:

4 P.D. PINION

$$4.0 / 40 = 1:1$$

6 P.D. PINION

$$6.0 / 4.0 = 3:2$$

DETERMINE REDUCER OUTPUT SPEEDS USING TOTAL
REDUCTION OF 1750 RPM INPUT & 60 RPM POL SPEED

$$\text{TOTAL REDUCTION } 1750 / \underline{60} = 29:1$$

REDUCER OUTPUT / 4 P.D. PINION - RATIO 4:4 :

$$\text{REDUCER OUTPUT SP'D} = \text{POL SPEED} \times \frac{4}{4} = 60 \text{ RPM}$$

$$\text{REDUCER RATIO} = \frac{\text{SP MTR}}{\text{SP RTO OUT}} = \frac{1750}{60} = \underline{\underline{29:1}}$$

CALCULATIONS FOR

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REDUCTION W/ 6 PD PINION - RATIO 3:2

REDUCER SPD OUT = POL SPD X GEAR RATIO

$$= 60 \times \frac{2}{3} = \underline{\underline{40 \text{ RPM}}}$$

REDUCER RATIO:

$$\text{RATIO IS } \frac{\text{SPEED INPUT}}{\text{SPEED OUTPUT}} = \frac{\text{MOTOR SPD}}{\text{RED SPD OUT}}$$

$$= \frac{1750}{40} = \underline{\underline{44:1}}$$

FROM RELANCE PD-29

REDUCER HP REQ'D FOR 4 PD PINION:-

SIZE	180 G 30
REDUCTION RATIO	30:1 (29:1 REQ'D)
SPEED OUTPUT	58 RPM (60 REQ'D)
MOTOR SPEED	1750 RPM
TORQUE OUTPUT	2443 IN-LB (2330 REQ'D)
OVERHUNG LOAD	2270 LB (1165 REQ'D)
HP REQ'D	<u>3.0</u>
	② F.c.p.

REDUCER HP REQ'D FOR 6 PD PINION:

SIZE	180 G 40
REDUCTION RATIO	40:1 (44:1 REQ'D)
SPEED OUTPUT	44 RPM (40 REQ'D)
MOTOR SPEED	1750 RPM
TORQUE OUTPUT	3095 IN-LB (3495 REQ'D)
OVERHUNG LOAD	2210 LB (1165 REQ'D)
HP REQ'D	<u>3.0 (+)</u>
	② F.c.p.

CALCULATIONS FOR			
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RECALCULATE USING CRUSHING LOAD OF 2341 LB

RED. TORQUE = TORQUE R.H. ROLL + TORQUE L.H. ROLL

TORQUE R.H. ROLL = $2341^{\#} \times .1541'' = 361 \text{ IN-LB}$

TORQUE L.H. ROLL = 361 IN-LB

REDUCER TORQUE = 722 IN-LB

TOOTH LOADS ON ROLL GEARS WITH $F = 2341 \text{ LB}$

$TL = \text{TORQUE} / P.D. \div 2$

$TL_{LH} = 361 \text{ IN-LB} / 4 \div 2 = \underline{\underline{181 \text{ LB}}}$

$TL_{RH} = \underline{\underline{181 \text{ LB}}}$

PINION TOOTHLOAD = $T_{RH} + T_{LH} = \underline{\underline{361 \text{ LB}}}$

NOTE: RH GEAR TRANSMITS FULL LOAD TO BOTH ROLL GEARS FROM DRIVE PINION.

REDUCER TORQUE

= $TL_{PINION} \times \text{PITCH RAD}$

REDUCER TORQUE AT 4 P.D. = $361^{\#} \times 2.0''$

= 722 IN-LB

REDUCER TORQUE AT 6 P.D. = $361^{\#} \times 3.0''$

= 1083 IN-LB

GENERAL ATOMIC COMPANY

CALCULATIONS FOR			
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USE SAME GEAR RATIOS AND REDUCER RATIOS
AS PREVIOUSLY

4" P.D. RATIO = 1:1

REDUCER RATIO = 29:1

6" P.D. RATIO 3:2

REDUCER RATIO = 44:1

REDUCER H.P. REQ'D FOR 4 P.D. & 6 P.D. FROM
FEL ANCE CATALOG P. U-29:

REDUCER H.P. FOR 4 P.D. :

SIZE	56 D 30	
REDUCTION RATIO	30:1	(29:1 REQ'D)
SPEED OUTPUT	58 RPM	(60 REQ'D)
MOTOR SPEED	1750 RPM	
TORQUE OUT	596 IN-LB	(722 REQ'D)
OVERHUNG LOAD	970 LB	(361 REQ'D)
H.P. REQ'D	3/4 (H)	
	(2) F _{MAX}	

OPTIONAL REDUCER AT 1 HP

SIZE	56 E 30	
TORQUE OUTPUT	820 IN-LB	(722 REQ'D)
OVERHUNG LOAD	1350 LB	(361 REQ'D)
HP REQ'D	1.0	

GENERAL ATOMIC COMPANY

CALCULATIONS FOR			
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REDUCER HP FOR G.P.D

SIZE	56E40	
REDUCTION RATIO	40:1	(44:1 REQ'D)
SPEED OUTPUT	44 RPM	
MOTOR SPEED	1750 RPM	
TORQUE OUT	778 IN-LB	(1083 REQ'D)
OVERHUNG LOAD	1360 LB	(361 REQ'D)
H.P. REQ'D	3/4	

OPTIONAL REDUCER AT 1 HP

SIZE	56E40	
TORQUE OUT	1051 IN-LB	(1083 REQ'D)
OVERHUNG LOAD	1340 LB	(361 REQ'D)
HP REQ'D	1.0	

CALCULATIONS FOR PARTICLE CRUSHER DRIVE - SUMMARY

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SUMMARY OF DRIVE OPTIONS - 2341 LB CRUSHING LOAD

MOTOR SPEED-1750, ROLL SPEED-60 RPM

SYSTEM	REQUIREMENTS				RELIANCE A108 P.D-29 (REF E-4) REDUCER SELECTION				RELIANCE A108 P.E-7 (REF E-4) REDUCER ACTUAL		
	Roll ^④ DEMAND H.P.	REDUCER		MAX TOOTH LOAD LB.	SIZE	REDUCT- ION RATIO	MOTOR SIZE H.P.	OVER- HUNG LOAD LB.	TORQUE OUT IN-LB	SPEED OUT RPM	H.P. OUT
		OUTPUT RPM.	TORQUE IN-LB								
DIRECT DRIVE	.88	60	721	180	56E30	30:1	1	1350	819	58	.76
					56D30	30:1	3/4	970	595	58	.55
PINION DRIVE 4" P.D	.88	60	722	361	56E30	30:1	1	1350	819	58	.76
					56D30	30:1	3/4	970	595	58	.55
6" P.D	.88	40	1083	361	56E40	40:1	1	1340	1050	44	.73
					56E40	40:1	3/4	1360	777	44	.54

NOTE: ^④ SEE CALC E-6, p 8

CALCULATIONS FOR PARTICULATE CRUSHER DRIVE - SUMMARY

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SUMMARY OF DRIVE OPTIONS - 7560 LB CRUSHING LOAD

1750 MOTOR SPEED - 60 ROLL SPEED

SYSTEM	REQUIREMENTS				REDUCER SELECTION				REDUCER - ACTUALS		
	ROLL [Ⓐ] DEMAND H.P.	REDUCER OUTPUT RPM	TORQUE IN-LB	MAX. TOOTH LOAD LB.	SIZE	REDUCT- ION RATIO	MOTOR SIZE H.P.	OVER- HUNG LOAD LB.	TORQUE OUT IN-LB	SPEED OUT RPM	H.P. OUT
DIRECT DRIVE	2.2	60	2330	582	180G30	30:1	3	2270	2440	58	2.26
PINION DRIVE											
4" P.D.	2.2	60	2330	1165	180G30	30:1	3	2270	2440	58	2.26
6" P.D.	2.2	40	3495	1165	180G40	40:1	3	2210	3095	44	2.15

NOTE Ⓐ. SEE CALC E-6, P 8

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CALCULATIONS FOR PARTICLE CRUSHER DRIVE - SELECTION			
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PARTICLE CRUSHER DRIVE SELECTION ASSUMING
A 3/4 HP MOTOR DRIVE & F_{MAX} PARTICLE CRUSHING:

THE PINION GEAR DRIVE WITH 6 PD PINION
IS FIRST CHOICE:

1. HP & TORQUE ARE UNDERPOWERED AT 60RPM
2. REDUCER OVERHUNG LOAD CAPACITY IS OK
3. GROWN TO 1 H.P. FACT, DONE WITHOUT
STRUCTURAL CHANGE SINCE 1 HP MOTOR HAS
SAME FRAME AS 3/4 HP AND THE SAME
REDUCER IS USED FOR BOTH 3/4 & 1 H.P. AT 40:1.
4. MANY POSSIBLE DEGREES OF FREEDOM FOR DISENGAGING
DRIVE PINION FROM ROLL DRIVE GEARS.

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CALCULATIONS FOR PARTICLE CRUSHER GEAR DESIGN

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REF. DOCUMENTS: OHIO GEAR CO CATALOG

REVIEWED BY

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NO. 640 RR, STOCK SPUR GEARS
(REF E-5)

APPROVED BY

DATE

USING 6" PD PINION & 4" PD ROLL GEARS,

SPEEDS & H.P. DEMANDS ARE AS FOLLOWS:

ROLL GEARS 4.0" P.D.SPEEDSH.P. DEMAND

60

.88

43

.63

30

.44

FROM
CALC
E-6,
p. 8DRIVE PINION 6.0" PD

40

.88

1) 3:2 RATIO

29

.63

20

.44

FROM
CALC
E-6,
p. 8

HORSEPOWER RATINGS OF STOCK STEEL SPUR GEARS

FROM OHIO GEAR CO REF FOR 0.40 CARBON STEEL GEAR.

LOG-LOG

IS SHOWN IN ATTACHED PLOT. STOCK STUB TOOTH FORM

INVESTIGATED, 20° STUB TOOTH FORM HAS HIGHER CAPACITY.

FROM OHIO GEAR DATA PLOT THE BDP - 20° STUB TOOTH

FORM WAS CHOSEN SINCE IT HAS A CAPABILITY OF APPROX.

TWO TIMES DEMAND AT OPERATING SPEEDS. SERVICE

FACTOR ASSUMED AS 1.0.

E-9

CALCULATIONS FOR PINION GEAR DESIGN - TOOTH STRENGTH			
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BEAM STRENGTH OF STRAIGHT SPUR PINION TOOTH:

$$W_b = sbp \left(\frac{2h^2}{3pe} \right) = sbp (y) \quad \text{[EQ 8-1 p 164]} \quad \text{REF}$$

WHERE s = ALLOWABLE TENSILE STRESS - TABLE 8-2 ^{REF}

b = BREADTH OF TOOTH (FACE WIDTH) = 1.25

p = CIRCULAR PITCH = $\frac{\pi \times P.D.}{N \& \text{TEETH}}$

y = FACTOR FOR TOOTH FORM, PRESS ANGLE & NO. OF TEETH (N) [SEE TABLE 8-1] ^{REF}

FROM TABLE 8-2 WITH STEEL GEAR MATERIAL, $s = 36,000$ P.S.I. ^{REF}

FROM TABLE 8-1 WITH 20° PRESS ANGLE, STUB TOOTH, 48 TEETH, $y = 0.150$ ^{REF}

$$W_b = 36,000 \times 1.00 \times \frac{\pi \times 6.0}{48} \times 0.150$$

$$= \underline{2121 \text{ LB PER INCH FACE WIDTH}}$$

DYNAMIC LOAD ON PINION GEAR TEETH FROM TOOTH LOAD:

$$W_d = \frac{0.05V(bc + W)}{0.05V + \sqrt{bc + W}} + W \quad \text{[EQ 8-2 p 165]} \quad \text{REF}$$

WHERE V = PITCH LINE VELOCITY FT/MIN

b = BREADTH OF TOOTH INCH

C = FACTOR FOR MAT'L'S, SYSTEM, FORM & ERROR IN ACTION [SEE TABLE 8-3] ^{REF}

e = ERROR IN ACTION FOR S.D.P. AT V USE LARGER OF 0.002 OR FROM FIG 8-5 ^{REF}

W = TANGENTIAL TOOTH LOAD - LB

CALCULATE FOR V WITH P.D. = 6", 15 SPEED
= 44 RPM (SEE REDUCED SUMMARY E-8 TO 10) ^{CALC}

GENERAL ATOMIC COMPANY

CALCULATIONS FOR PINION GEAR DESIGN - TOOTH STRENGTH

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$$V = \frac{\pi P D}{12} \times 44 = \frac{\pi (6)}{12} \times 44 = 69 \text{ FT/MIN}$$

FROM REF FIG B-5 & $V = 69$:

$$Q = 0.005$$

FROM REF TABLE B-3, STUB TOOTH,
20° STUB TOOTH, $Q = 0.005$;

$$Q = 8600$$

FROM CALL. REDUCED SUMMARY E-8, p 22 & p 23.

$$\begin{aligned} W &= \text{TOOTH LOAD} \\ &= 1165 \text{ LB FOR } 6 \text{ PD, } 3 \text{ HP} \\ &= 361 \text{ FOR } 3/4 \text{ HP} \end{aligned}$$

$$0.05 V (bC + W) = .05 (69) [1.0 \times 8600 + W]$$

$$\begin{aligned} &= .05 (69) (9765) \text{ OR} \\ &= .05 (69) (8961) \\ &= 33689 \text{ OR } 30915 \end{aligned}$$

$$0.05 V + \sqrt{bC + W} = .05 (69) + \sqrt{1.0 \times 8600 + W}$$

$$\begin{aligned} &= .05 (69) + \sqrt{9765} \text{ OR} \\ &= .05 (69) + \sqrt{8961} \end{aligned}$$

$$\begin{aligned} &= 3.45 + 98.66 \text{ OR} \\ &= 3.45 + 94.82 \end{aligned}$$

$$102.11 \text{ OR } 98.27$$

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CALCULATIONS FOR			
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$$W_d \text{ worst } \frac{3}{4} \text{ HP} = \frac{33689}{102.11} + 1165 = \underline{\underline{1495 \text{ LB/1" FACE}}}$$

$$W_d \text{ nominal } \frac{3}{4} \text{ HP} = \frac{30915}{98.27} + 361 = \underline{\underline{676 \text{ LB/1" FACE}}}$$

ACCORDING TO REF P 167:

$$b \leq 4 \text{ C.P.} = \frac{4 \pi D P}{N} = \frac{4 \pi \times 6}{48} = \underline{\underline{1.57 \text{ IN}}}$$

$$W_b \geq 1.5 W_d \text{ FOR SHOCK LOAD (START UNDER LOAD CONDITION)}$$

$$2121 \leq 1.5 (1495)$$

$$W_b = 1.41 (W_d) \text{ WITH 1" FACE O.K.}$$

$$2121 \geq 1.5 (676)$$

$$W_b = 3.14 (W_d) \text{ W/ 1" FACE O.K.}$$

CHECK LOAD LIMIT BASED ON WEAR:

$$W_w = D b K Q \quad [\text{REF } \text{B-3 p 167}]$$

WHERE

- D = P.D OF PINION (USE 6.0)
- b = FACE WIDTH (USE 1.0)
- K = LOAD FACTOR [TABLE B-4 p 168] FOR GEARING, MAT'L & TOOTH FORM
- BHN OF 150. = 41
- Q = REDUCTION RATIO FACTOR
- = $\frac{2 N_G}{N_G + N_P}$ FOR SPUR GEARS

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CALCULATIONS FOR			
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$$N_G = \text{ROU GEAR TEETH} = D.P \times P.D.$$

$$= 8 \times 4.0 = 32 \text{ T}$$

$$N_p = 8 \times 6.0 = 48 \text{ T}$$

$$Q = \frac{2(32)}{32+48} = 0.8$$

$$W_w = 6.0" \times 1.0" \times 41 \times 0.8 = 197 \text{ LB/INCH FACE}$$

$$W_w \geq W_d ; 197 \geq 676 \quad \text{N.G.}$$

$$\geq 1495 \text{ (unstress case)}$$

THIS INDICATES THAT TOOTH WEAR MAY BE LIMITING CONDITION. SELECT BETTER GEAR MAT'L AND WIDER TEETH TO INCREASE W_w .

$$\left[\text{i.e. } b = 1.25 \text{ IN } \& \text{ 250 BHN MAT'L } W_w = 780 \right]$$

$$\geq 676$$

THIS IS FOR 10^6 CYCLE OPERATION.

ASSUME A 10 YR LIFE AND 1 HR CRUSHING FOR 5 HR BURNER OPERATION:

$$10 \text{ YR} \times 2080 \text{ HR/YR} = 20800 \text{ BURNER ON TIME}$$

$$20800 / 5 = 4160 \text{ HR OF CRUSHER OPERATION}$$

$$1 \times 10^6 \text{ CYCLES IS } 1 \times 10^6 \text{ REV} \div 40 \text{ RPM} \times 60 = 416.7 \text{ HR} = 2.4 \text{ MONTHS}$$

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CALCULATIONS FOR DESIGN OF CRUSHING ROLLS - STRESS CONCENTRATIONS			
EQUIP. NO.	PROJ. NO.	CALC NO. E-10	PAGE 31 OF
PREPARED BY	DATE	REF. DOCUMENTS: R.F. PETERSON, "STRESS CONCENTRATION DESIGN FACTORS"	
REVIEWED BY	DATE	REF A-4	
APPROVED BY	DATE		

FROM DESIGN CRITERIA D.C. 520001 A & DESIGN SPECIFICATION (APPENDIX A & B):

Roll DIA = 4.0"

Roll LGTH = 4.0"

BEG SEAT DIA = 2.0"

Roll MAT'L (1) 1020 STL (ULT = 55,000 psi)

" " (1) 4340 STL (ULT = 108,000 psi)

CALCULATE STRESS CONCENTRATION FACTORS FOR SHOULDER FILLETS - PETERSON CH 3(B) & (C), EQ 57:

$$K_{t'L} = 1 + (K_t - 1) \left(\frac{K_{tb} - 1}{K_{ta} - 1} \right)$$

$K_{t'L}$ = FACTOR COMBINING NORMAL STRESS AND FAILURE CRITERION FOR NARROW SHOULDER

$$D/d = \frac{4}{2} = 2.0$$

$$r/d = \frac{0.125}{2.0} = .063$$

[ASSUMES $1/8" = r$]

K_t = COMBINED FACTOR FOR NORMAL STRESS AND FAILURE CRITERION FOR WIDE SHOULDER

$$L/D = \frac{4}{4} = 1.0$$

K_{ta} = FACTOR FOR NORMAL STRESS, $r/d \neq 1/0 = 2.0$

$$K_t \text{ FROM FIG 66} = 1.83$$

K_{tb} = FACTOR FOR NORMAL STRESS, $r/d \neq 1/0$ DESIRED

$$K_{tb} \text{ FROM FIG 62} = 2.12$$

$$K_{ta} \text{ FROM FIG 62} = 2.18$$

$$\text{SOLVING } K_{t'L} = 1 + (1.83 - 1) \left(\frac{2.12 - 1}{2.18 - 1} \right) = \underline{1.79}$$

CALCULATIONS FOR <u>DESIGN OF ROLLS - FATIGUE STRENGTH</u>			
EQUIP. NO.	PROJ NO	CALC. NO. <u>E-10</u>	PAGE <u>32</u> OF
PREPARED BY	DATE	REF. DOCUMENTS TIMOSHENKO & MACH COLLUMEN "ELEMENTS OF STRENGTH OF MATERIALS" FATIGUE OF METALS, REF E-7 AND R.E. PETERSON REF A-4	
REVIEWED BY	DATE		
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SOLVE FOR K_{tL} AND USE LARGEST FACTORS OF K_t & $K_{t'}$: EQ 56 & EQ 57 - PETERSON

$$K_{tL} = 1 + (K_t - 1) \left(\frac{K_{tb} - 1}{K_{ta} - 1} \right)$$

$$K_{ta} = \text{AS BEFORE } 2.18$$

$$K_t \text{ FROM FIG 65} = 2.0$$

$$K_{tb} = \text{AS BEFORE } 2.12$$

$$K_{tL} = 1 + (2.0 - 1) \left(\frac{2.12 - 1}{2.18 - 1} \right) = \underline{\underline{1.95}}$$

DETERMINE NOTCH SENSITIVITY (q) WITH $K_t = K_{tL}$ & USING ANNEALED STEEL & 0.125 IN R:

$$q = 0.9 \text{ FROM FIG 13 AND EQ 15, PETERSON p 10}$$

$$K_{tf} = q(K_t - 1) + 1 = 0.9(1.95 - 1) + 1 = \underline{\underline{1.86}}$$

FIND FATIGUE STRENGTH:

$$S_{FAT} = \frac{\text{ENDURANCE LIMIT}}{K_{tf}}$$

S_e IS 0.4 TO 0.5 X ULTIMATE T.S. - TIMOSHENKO p. 319

$$1020 \text{ ROLL } S_e = 55,000 \times 0.4 \text{ (MACHINED SHOULDER)}$$

$$41340 \text{ ROLL } S_e = 108,000 \times 0.4 \text{ (MACHINED SHOULDER)}$$

THEN FATIGUE STRENGTH IS:

$$S_{FAT}(1020) = \frac{55,000 \times 0.4}{1.86} = \underline{\underline{11,830 \text{ psi}}}$$

$$S_{FAT}(41340) = \frac{108,000 \times 0.4}{1.86} = \underline{\underline{23,230 \text{ psi}}}$$

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CALCULATIONS FOR DESIGN OF ROLLS - WORKING STRESS			
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WE WILL USE AS WORKING STRESSES
THE FOLLOWING:

A.I.S.I. 1020 ONE ROLL 11,500 PSI

A.I.S.I. 4340 ONE ROLL 23,000 PSI

NOTE: FILLET AREAS ARE NOT HEAT TREATED.

E-10

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CALCULATIONS FOR ROLL DESIGN - DEFLECTION UNDER LOAD			
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MAXIMUM DEFLECTION UNDER UNIFORM DISTRIBUTED LOAD ACROSS FULL ROLL FACE WIDTH IS SUM OF MAXIMUM SHEAR DEFLECTION AND MAXIMUM BENDING DEFLECTION, USING LARKE CHPT 3, P 71, EQ (2):

$$\Delta_y (\max) = \Delta_y B (\max) + \Delta_y S (\max) \quad \text{AND}$$

$$\Delta_y B = \text{DEFLECTION DUE TO BENDING} \quad (\text{in})$$

$$\Delta_y S = \text{" " " " SHEAR} \quad (\text{in})$$

$$P_c = \text{LOAD ON ROLLS - UNIFORMLY DISTRIBUTED} \quad (\text{LB})$$

$$p = \text{SHEAR ALTERNATING STRESS} \quad (\text{psi})$$

$$W = \text{ROLL WIDTH} \quad (\text{in})$$

$$n = \text{" NECK LGTH TO CTR OF BRG} \quad (\text{in})$$

$$D = \text{ROLL DIAMETER} \quad (\text{in})$$

$$d = \text{" NECK DIAMETER} \quad (\text{in})$$

$$L = \text{CTR TO CTR OF BRGS} = W + 2n \quad (\text{in})$$

$$r = \text{fillet radius (D to d)} \quad (\text{in})$$

$$E = \text{YOUNG'S MODULUS OF ELASTICITY} \quad (\text{psi})$$

$$N = \text{MODULUS OF RIGIDITY} = 2E/5 \quad (\text{psi})$$

$$I_D = \pi D^4 / 64 \quad (\text{in}^4)$$

$$I_d = \pi d^4 / 64 \quad (\text{in})^4$$

$$\Delta = \text{STRESS CONCENTRATION FACTOR} \quad \text{DIMENSIONLESS}$$

MAXIMUM DEFLECTION UNDER UNIFORM DISTRIBUTED LOAD IS AT CENTER OF ROLL AT $L/2$.

DEFLECTION DUE TO BENDING - LARKE p. 71 EQ (2a):

$$\Delta_y B (\max) = \frac{P_c W^2}{6 \pi r D^4} (5W + 24n) \quad (\text{in})$$

CALCULATIONS FOR <u>ROLL DESIGN - DEFLECTIONS</u>			
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DEFLECTION DUE TO SHEAR - LARKE P 71 EQ (2b):

$$c_{yS}(\max) = \frac{P_c w}{2 \pi N D^2} \quad (1n)$$

COMBINED DEFLECTION - LARKE P 71, EQ (2):

$$c_y(\max) = c_{yB}(\max) + c_{yS}(\max) \quad (1n)$$

ROLL LOAD - P_c - LARKE P 73, EQ (3)

$$P_c = \pi d^3 p / 16 n \Delta \quad (LB)$$

SOLVE FOR STRESS CONCENTRATION FACTOR, D ; ROLL LOAD, P_c ; DEFLECTIONS DUE TO BENDING & SHEAR, $c_{y(\max)B}$, $c_{y(\max)S}$; MAXIMUM DEFLECTION DUE TO COMBINED BENDING & SHEAR, $c_y(\max)$. USE THE FOLLOWING:

$$\begin{aligned} D &= 4.0 \text{ in.} & r &= 0.125 \text{ in.} & n &= 0.25 \text{ in. (1/2" WIDE BRG)} \\ d &= 2.0 \text{ in.} & w &= 4.0 \text{ in.} & L &= w + 2n = 4.5 \text{ in.} \end{aligned}$$

$$E = 29 \times 10^6 \text{ psi}$$

$$N = 2E/5 = 11.6 \times 10^6 \text{ psi}$$

$$\begin{aligned} p &= 11,500 \text{ psi FOR 1020 STEEL (SEE CALC P. 32)} \\ &= 23,000 \text{ psi FOR 4340 STEEL (SEE CALC P. 32)} \end{aligned}$$

$$I_D = \frac{\pi D^4}{64} = 12.57 \text{ in}^4$$

$$I_d = \frac{\pi d^4}{64} = 0.79 \text{ in}^4$$

$$r/d = 0.125/2.0 = 0.063$$

$$h = (D-d)/2 = 1.0$$

$$h/r = 8.0$$

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CALCULATIONS FOR <u>Roll Design - Deflection & Max Load</u>			
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STRESS CONCENTRATION FACTOR - LARKE p 75

USING $h/r = 8.0$ & $r/d = .063$ IN FIG 3.4 (LARKE)
 MAX h/r SHOWN IS 5.0. ASSUME $r/d = 0.05$ CURVE
 TAKES SAME SHAPE AS OTHER r/d PLOTS THEN,

$$\Delta = 2 \text{ TO } 3 \text{ USE } 2.5$$

ROLL LOAD (P_c) - LARKE EQ 3 p 73

$$P_c = \pi d^3 \times p / 16 n \Delta$$

FOR 1020 STEEL $p = 11,500 \text{ psi}$

$$P_{c \text{ 1020}} = \underline{\underline{28,900 \text{ LBS}}}$$

FOR 4340 STEEL $p = 23,000 \text{ psi}$

$$P_{c \text{ 4340}} = \underline{\underline{57,800 \text{ LBS}}}$$

USING THESE ROLL LOADS DEFLECTIONS ARE
 AS FOLLOWS - LARKE:

1020 STEEL ROLL

$$\begin{aligned} C_y B(\text{max}) &= \frac{P_c w^2}{6 \pi E D^4 (5w + 2n)} \\ &= .0000859 \text{ in} = 85.9 \times 10^{-6} \text{ in} \end{aligned}$$

$$\begin{aligned} C_y S(\text{max}) &= \frac{P_c w}{2 \pi n D^2} \\ &= .000099 \text{ in} = 99 \times 10^{-6} \text{ in} \end{aligned}$$

$$C_y(\text{max}) = (85.9 + 99) \times 10^{-6} = 185 \times 10^{-6} = \underline{\underline{.000185 \text{ INCHES}}}$$

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CALCULATIONS FOR <u>Roll DESIGN - MAXIMUM DEFLECTION</u>			
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4340 Roll

$$C_y B(\max) = \frac{P_c w^2}{6\pi E D^4} (5w + 24n) = .000172 \text{ in} \\ = 172 \times 10^{-6} \text{ in}$$

$$C_y S(\max) = \frac{P_c \times w}{2\pi n D^2} = 198 \times 10^{-6} = .000198 \text{ in}$$

$$C_y(\max) = C_y S + C_y B = 370 \times 10^{-6} = \underline{\underline{.000370 \text{ in.}}}$$

THIS ASSUMES LOADS BASED UPON FATIGUE STRENGTH OF THE ROLL MATERIALS. DEFLECTIONS WITH LOADS IMPOSED BY PARTICLE CRUSHING ARE A FRACTION OF THESE SINCE CRUSHING LOADS MAY BE ONLY 7560 LBS MAX (CALC P.4)

GENERAL ATOMIC COMPANY

CALCULATIONS FOR <u>ROLL DESIGN - DIAMETER CHANGE WITH TEMPERATURE</u>			
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PREPARED BY	DATE	REF. DOCUMENTS: DESIGN CRITERIA - FUEL PARTICLE CRUSTER DC 5200.21-A APPENDIX A	
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ROLL DIAMETER AT EQUILIBRIUM TEMPERATURE

$$D_{\text{ORIGINAL}} = 4.0 \text{ IN.}$$

$$\alpha_{\text{STEEL}} = 8.0 \times 10^{-6} \text{ IN/IN/}^{\circ}\text{F}$$

$$T_{\text{FINAL}} = 115^{\circ}\text{F FROM DESIGN CRITERIA}$$

$$\begin{aligned} D_{\text{FINAL}} &= D_{\text{ORIG}} + \alpha (D_{\text{ORIG}}) (T_{\text{F}} - T_{\text{ORIG}}) \\ &= 4.0 + 8.0 \times 10^{-6} (4.0) (115 - 60) \\ &= 4.00176 \text{ IN} \end{aligned}$$

CHANGE IN CRUSHING GAP IS EQUAL TO THE CHANGE IN DIAMETER OF ONE ROLL. ROLL GAP WILL DECREASE BY NEARLY .002 INCH IF ROLLS REACH EQUILIBRIUM AT 115°F.

APPENDIX F
ENGINEERING DRAWINGS

1. DIMENSIONING & TOLERANCING PER ANSI Y14.5
2. REMOVE ALL BURRS & SHARP EDGES
3. ALL WELDS PER AWS D1.1
4. VENDOR TO SUPPLY DOCUMENTATION OF DIMENSIONS AFTER FINAL MACHINING.

① COVER PLATE ASSY

1	4	5211007-4	FLANGE	3/8 R	CARBON STEEL	ASTM-A36
1	3	5211007-3	PIPE	2 NOM SCH 40	CARBON STEEL	ASTM-AE3
1	2	5211007-2	PLATE -TOP	1" R	CARBON STEEL	ASTM-A36
/	1	5211007-1	COVER PLATE ASSY			

1	ITEM	PART NO.	DESCRIPTION	MATL
LIST OF MATERIAL				

										REQD/ASSEMBLY										LIST OF MATERIAL									
										UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: DECIMALS .XXXS .015 JOH .03 FRACTIONS 1/16 3/32 ANGLES & 1° ALL MACHINED SURFACES 32/										COVER PLATE ASSY- PARTICLE CRUSHER									
										NEXT ASSY 5211006										GENERAL ATOMIC COMPANY SAN DIEGO, CALIFORNIA									
APPD FOR CONSTRUCTION										JAN 10-7-68										DRAWING NUMBER 852 5211007									
DATE										ISSUE DESCRIPTION										SCALE 1/1 ISSUE A									

APPROVAL LEVEL No. 1

EST. WGT. 12 LBS

SHEET 1 OF 1

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3 SHIM THICKNESS TO BE DETERMINED AT ASSY.

[illegible]

REQD/ASSEMBLY					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.					
TOLERANCES:					
DECIMALS .XX $\pm$.015 XX $\pm$.0					
FRACTIONS $\pm$ 1/16					
ANGLES $\pm$ 1°					
ALL MACHINED SURFACES $\sqrt{\text{175}}$					
NEXT ASSY 5211006

**GENERAL ATOMIC
COMPANY**
SAN DIEGO, CALIFORNIA

	DRAWING NUMBER	ISSUE
852	5211010	A

EST. WGT. 1 LB. EA. SHEET 1 OF 1
APPROVAL LEVEL NO. 1

NOTES:

1. DIMENSIONING & TOLERANCING PER PER ANSI Y14.5
2. REMOVE ALL BURRS & SHARP EDGES
3. FLAME HARDEN 4" DIA ROLL SURFACE. PRODUCE A .060 TO .070 THICK HARDENED SHELL TO RC 58-60 THROUGHOUT THE CASE THICKNESS
4. CARBURIZE & HARDEN 4" DIA ROLL SURFACE. PRODUCE A .060 TO .070 THICK HARDENED SHELL TO RC 58-60 THROUGHOUT THE CASE THICKNESS
5. CONTROL SPECIMEN REQUIRED
6. SOURCE: OHIO GEAR, INC., LIBERTY, S.C., GEAR NO. TST-832
7. SOURCE: AUTO-DIESEL PISTON RING CO., CLEVELAND, OHIO
8. FOR ITEM 3 IDENTIFY: ROLL NO. 4340-1
9. FOR ITEM 4 IDENTIFY: ROLL NO. 1015-1
10. ALL MACHINED FINISHES ARE AS SHOWN OR BETTER
11. VENDOR TO SUPPLY DOCUMENTATION OF DIMENSIONS AFTER FINAL MACHINING.

17	5211011-17	ROLL & GEAR ASSY.		
16	5211011-16	ROLL & GEAR ASSY.		
15	5211011-15	ROLL & GEAR ASSY.		
14	5211011-14	ROLL & GEAR ASSY.		
13	5211011-13	ROLL	ALLOY STEEL	AISI 4340
12	5211011-12	ROLL		
11	5211011-11	ROLL		
10	5211011-10	ROLL	ALLOY STEEL	AISI 4340
9	-9	WASHER-FLAT 5/16 NOM.	STEEL	COML
8	-8	SCR-HEX HD CAP 5/16-18 X 3/4	STEEL	COML
7	-7	SCR-WDL SET 5/16-18 X 3/4	STEEL	COML
6	-6	RING 3.75 O.D. .060 THK. 23 RIDE		GA SUPPLIED
5	-5	SPUR GEAR		GA SUPPLIED
4	-4	ROLL	CARBON STEEL	AISI 1015-1020
3	-3	ROLL	ALLOY STEEL	AISI 4340
2	-2	ROLL & GEAR ASSY (FSV FERTILE)		
1	5211011-1	ROLL & GEAR ASSY (FSV FERTILE)		

17	46	13	14	2	1	ITEM	PART NO.	DESCRIPTION	MATL		
REQD/ASSEMBLY						LIST OF MATERIAL					
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: DECIMALS .XXX ± .015, .XXX ± .03 FRACTIONS ± 1/16 ANGLES ± 1° ALL MACHINED SURFACES 32/ NEXT ASSY. 5211006						ROLL & GEAR ASSY- PARTICLE CRUSHER				GENERAL ATOMIC COMPANY	
										SAN DIEGO, CALIFORNIA	
										DRAWING NUMBER	ISSUE
SCALE 1/2						852			5211011	C

NOTES:
1. MOTOR TO BE PLANSRD MOUNTED TO REDUCER
2. RE-MOV' BURETS & SHARP EDGES
3. GEAR DATA:
GEO CARBON STL. OR 4011
6" A.D., 8" D.A., 10" A.A., 1 1/2" FACE, NO TSTONS
1.125/1.127 800P, 1/4" 30. EFFICIENCY, SPT. JOURNAL
SOURCE:
OHIO GEAR, LIBERTY, S.C.
REDUCER DATA:
4011, NO. 56640, STOCK NO. 471619
SOURCE:
RELIANCE ELECTRIC CO., CLEVELAND OHIO.
MOTOR DATA:
3/4 HP, 3C, 1750 RPM, C. FACE, NO. 471619, 100% EFFICIENCY
SOURCE:
RELIANCE ELECTRIC CO., CLEVELAND OHIO.

ITEM	QTY	DESCRIPTION	MATL.
1	1	5200002-5 MOTOR	
2	1	5200002-4 REDUCER	
3	1	5200002-3 SPUR GEAR	
4	1	5211006-1 PARTICLE CRUSHER ASSY	
5	1	5200002-1 PARTICLE CRUSHER EQUIP ASSY	

REV	DATE	DESCRIPTION	BY	CHK	APP	APP
1	10/1/61	APP FOR CRUS	W. J. B. J.			

PARTICLE CRUSHER EQUIPMENT ASSY

GENERAL ATOMIC COMPANY

2.011 II

SHWT 1001

APR 1961

	1	3	5211008-3	FLANGE	CARBON STEEL	ASTM-A36	
	1	2	5211008-2	PLATE	CARBON STEEL	ASTM-A36	
	/	1	5211008-1	END BODY ASSY			
	-1						
REQD/ASSEMBLY			ITEM	PART NO.	DESCRIPTION	MATL	SPEC
LIST OF MATERIAL							
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: DECIMALS .XXX ± .015 JOX & .03 FRACTIONS 3/16 ± .010 ANGLES 2° ± .05 ALL MACHINED SURFACES ✓			END BODY ASSY- PARTICLE CRUSHER				GENERAL ATOMIC COMPANY SAN DIEGO, CALIFORNIA
NEXT ASSY 5211006							
SCALE 1/1			DRAWING NUMBER		ISSUE		
			852		5211008 A		

APPROXIMATE LENGTH No. 1 EST. WGT. 43LBS SHEET 1 OF 1