176
9-26-79

LH. 92

GA-A15447
UC-77

MASTER

HTGR FUEL PARTICLE CRUSHER - MARK 2 DESIGN

by
JOHN W. BAER

Prepared under
Contract DE-AT03-76SF71053
for the San Francisco Operations Office
Department of Energy

DATE PUBLISHED: JUNE 1979

GENERAL ATOMIC COMPANY

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy \$4.50; Microfiche \$3.00

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

GA-A15447
UC-77

MASTER

HTGR FUEL PARTICLE CRUSHER - MARK 2 DESIGN

by
JOHN W. BAER

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared under
Contract DE-AT03-76SF71053
for the San Francisco Operations Office
Department of Energy

GENERAL ATOMIC PROJECT 3261
DATE PUBLISHED: JUNE 1979

GENERAL ATOMIC COMPANY

1

2

ABSTRACT

The double-roll crusher for fracturing the silicon carbide coatings of high-temperature gas-cooled reactor (HTGR) fuel particles has been redesigned to improve the equipment. The housing was simplified and reduced to a two-piece assembly; the bearings were changed to accommodate thermal effects; the bearing protection seals were improved with triple redundancy; the bearing preload arrangement was simplified and improved; and localized wear areas were reinforced with better materials or special treatment. In addition, the crusher drive was changed for improved characteristics and an increase in power.

General Atomic Company (GA) has been testing fixed-gap, double-roll crushers for crushing fuel particles since 1970. This work, as part of technology development for HTGR fuel recycling, has been funded by the Department of Energy (DOE) to develop a crusher to receive burned-back fuel particles [typically 500 μm (0.020 in.) diameter] and to crush the particle silicon carbide coatings to expose the inner carbon and fuel for fluid bed combustion.

Basic crusher development has been performed at GA and at government laboratories using roll crushers of various designs. These designs evolved into the engineering-scale reference, fuel-particle crushers designed and built for the GA dry head-end, cold pilot recycle plant, which was successfully demonstrated in San Diego. Operation of this plant and the particle crusher indicated a need for crusher system modifications and improvements. These changes have been incorporated into the advanced particle crusher described in this topical report.

1

2

3

4

CONTENTS

ABSTRACT	iii
1. INTRODUCTION AND SUMMARY	1
2. PROCESS DESCRIPTION.	3
3. EQUIPMENT DESCRIPTION, REFERENCE DESIGN.	5
4. DESIGN FACTORS	8
4.1. General Requirements	8
4.2. Equipment Design Requirements.	8
4.3. Operational Requirements	10
5. TESTS.	11
5.1. Background Tests	11
5.1.1. GA Tests	11
5.1.2. Oak Ridge National Laboratory Tests.	11
5.1.3. Idaho National Engineering Laboratory Tests.	12
5.1.4. Test Results, Background Tests	12
5.1.5. Testing Information	12
5.2. Operational Tests, Reference Crusher	13
5.2.1. FSV Fertile Particle Crushing.	13
5.2.2. FSV and LHTGR Fissile Particle Crushing.	14
5.2.3. Test Results, FSV Fertile- and Fissile-Fuel Particles.	14
5.2.4. Sequential Operations.	19
5.2.5. Test Results, Sequential Operations.	21
6. FACTORS LEADING TO IMPROVED DESIGN	23
7. DESIGN DESCRIPTION, MARK 2 CRUSHER	24
7.1. Crusher Module	24
7.2. Crusher Drive and Bearings	25
7.3. Improved Design Description.	26
7.3.1. Bearing Design	27
7.3.2. Crusher Module Housing	27
7.3.3. Crushing Rolls	28

8. SUMMARY OF THE MARK 2 DESIGN	29
9. FUTURE WORK.	30
ACKNOWLEDGEMENTS	31
REFERENCES	32
APPENDIX A: ENGINEERING DRAWINGS.	A-1

FIGURES

1. Fuel particle crusher and drive motor	6
2. Double-roll particle crusher.	7
3. Fuel particle crusher product size distributions for various throughput rates.	16
4. Size distributions, crushed WAR particles	17
5. Feed and product size distributions, FSV fissile particle crusher	18

TABLE

1. Side body wear data, fertile particle crusher	20
--	----

1. INTRODUCTION AND SUMMARY

This topical report describes the Mark 2 advanced fuel-particle crusher. The design of the Mark 2 evolved from engineering-scale reference particle crushers, which were fabricated, tested, and used in the operation of the existing dry head-end cold pilot plant at General Atomic Company (GA). Modifications to the reference design were made to improve equipment reliability, performance, operability, and the cost effectiveness.

A design evaluation assessed the existing reference fuel-particle crushers for prototype suitability for the high-temperature gas-cooled reactor (HTGR) recycle reference facility (HRRF) system. The study recommended alternatives where the reference designs were considered unsuitable.

Additionally, reference particle-crusher operations and crusher tests were reviewed for necessary crusher improvements or modifications. These reviews were directed primarily at the crusher drive-power requirements, the wear of the crusher housings and rolls, and the effectiveness of the sealing of the bearings from the abrasive crusher-product-stream dust. At the same time, the manufacturing costs and complexities and the ease of roll-bearing preload adjustment were integrated into the redesign considerations.

As a part of the consolidated fuel recycle program, under the direction of the Department of Energy (DOE), GA has the responsibility for developing a prototype HRRF using unirradiated fuels.

The overall program objective is to demonstrate the technology for HTGR-fuel recycle 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.

2. PROCESS DESCRIPTION

The overall purpose of the dry head-end systems in HTGR fuel reprocessing is to prepare the fuel particles for dissolution and subsequent recovery of the fissionable materials by solvent extraction. The flowsheet is comprised of fuel-element size reduction, crushed fuel-element burning, particle classification, particle crushing, and crushed particle burning. These unit operations are connected by pneumatic solids handling systems.

The fuel elements are reduced to less than 4750 μm (0.1875 in.) fragments by a series of two overhead eccentric jaw crushers and a double-roll crusher. The crushed product is screened to remove the +4750 μm fragments. These are further crushed in a single-roll crusher. This system has been designated UNIFRAME because of the integration of all the equipment into the gravity-fed, specially designed, single structure.

The crushed material is pneumatically conveyed to a product bunker for storage and then to the feed bunker of the primary burner.

The crushed fuel is fluidized with carbon dioxide in the primary burner and heated by an induction heater. Oxygen is introduced to begin combustion. The fluidized bed is maintained at $\sim 900^{\circ}\text{C}$ ($\sim 1652^{\circ}\text{F}$) by a combination of induction heating and air cooling. As the graphite and outer carbon coatings on the particles are burned off, the product is pneumatically conveyed to a product bunker for storage and then to the feed bunker of the air classifier.

The burned-back fuel particles are fed into a moving air stream within a zig-zag classification column. The lighter fissile particles, which are entrained in the upward flowing gas, are separated from the

gas and fall into a receiving bunker. The denser fertile particles fall through the gas stream into a separate receiving bunker.

The burned-back, silicon-carbide-coated fissile particles have inner carbon coatings which must be burned off to avoid interference in the solvent extraction process. These particles are pneumatically conveyed to the particle-crusher feed bunker, then fed to the double-roll fuel-particle crusher, where the outer silicon carbide coatings are fractured to expose the inner carbon coatings and fuel.

The crushed particles are gravity-fed into the fuel-particle secondary-burner feed hopper. The entire batch is fed to the secondary burner and fluidized with carbon dioxide. The fluidized bed of crushed particles is heated by an induction heater to ignition temperature, and oxygen is introduced to begin combustion. The bed is maintained at $\sim 900^{\circ}\text{C}$ ($\sim 1652^{\circ}\text{F}$) by a combination of induction heating and air cooling. After combustion is complete, the product is pneumatically conveyed to the secondary-burner product bunker ready for dissolution.

3. EQUIPMENT DESCRIPTION, REFERENCE DESIGN

The reference fuel-particle crusher is a small, compact, double-roll crusher with a fixed crushing gap. The hardened-steel crushing rolls are 10 cm (4 in.) in diameter by 10 cm (4 in.) long. The crusher operates semicontinuously in line with the solids handling system to produce feed for the secondary burner. Figure 1 shows the fuel-particle crusher and drive motor mounted in place on the secondary-burner hopper. The double-roll fuel-particle crusher is shown schematically in Fig. 2.

Fuel particles enter the fuel-particle roll crusher by gravity flow from the particle-crusher feed bunker. The crushing action is produced by the contact between the two counter-rotating roll surfaces and the fuel particles, which forces the fuel particles through the narrow gap between the rolls. The crushed fuel particles are discharged by gravity into the secondary-burner feed hopper. The 10-cm (4-in.) diameter rolls, driven by a variable-speed drive system, are contained in an enclosure that connects the crushing system to the particle-crusher feed bunker and the secondary-burner feed hopper. This enclosure 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 ones of different diameters.

In normal operation, the drive motor is activated, the drive controller is set for the desired roll rpm, 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; they are choke-fed by gravity to the crushing area, where the silicon-carbide coatings of the particles are fractured. The crushed material is then discharged into the burner feed bunker.

Fig. 1. Fuel particle crusher and drive motor (mounted on secondary burner feed hopper)

Fig. 2. Double-roll particle crusher

4. DESIGN FACTORS

4.1. GENERAL REQUIREMENTS

The reference design of the fuel-particle roll crusher was 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 knowledge derived from work at GA and work done by others on fuel particle crushing as a basis, a design criteria document for the reference crusher was prepared. 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 prototypical for actual hot-cell equipment and which would be usable in the GA 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.

4.2. EQUIPMENT DESIGN REQUIREMENTS

Equipment design requirements for the reference fuel-particle crusher are given below:

1. Accepts Fort St. Vrain (FSV) fertile and fissile and large high-temperature gas-cooled reactor (LHTGR) fissile fuel particles and fractures the outer silicon-carbide coating to expose the thorium carbide, the uranium carbide, and the inner carbon coatings for fluidized-bed combustion.

2. Crushes fuel particles on a semicontinuous basis in 60 kg (132.27 lb) batches at a minimum rate of 30 kg/h (66 lb/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 in a hot-cell environment of up to 46°C (115°F).
8. Has long-wear materials with tolerance for the hot cell operating environment.
9. Is capable of inert-gas blanketing or separate-gas purging to 6.9 kPa (1 psig) maximum.
10. Possesses a minimal total volume of contaminated waste for disposal.
11. Uses standard commercial components, materials, and processes wherever possible.
12. Possesses as a design objective the improvement of equipment normal service life, reliability, and availability through substitution of more suitable materials, seals, or bearings when tests indicate the need.

4.3. OPERATIONAL REQUIREMENTS

Operational requirements for the reference fuel particle crusher are listed below:

1. Is adaptable to remote operation and maintenance and suitable for high-radiation environments.
2. Permits maximum special nuclear 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 personnel protection from radiation, airborne radioactive materials, and other industrial hazards.

5. TESTS

5.1. BACKGROUND TESTS (Ref. 1)

5.1.1. GA Tests

GA has tested double-roll crushers for fragmenting unirradiated, silicon-carbide-coated fuel particles since 1970. Subsequently, GA has continued fuel-particle crushing tests with double-roll crushers in support of the Consolidated Fuel Recycle Program under contract DE-AT03-76SF71053 for the San Francisco Operations Office of the U.S. Department of Energy.

Particle crushing tests at GA were done in crushers having 7.6 cm (3 in.) diameter by 2.5 cm (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.

5.1.2. 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 20.3 cm (8 in.) diameter by 5 cm (2 in.) wide smooth steel rolls. This led to the testing of an improved crusher design having 30.5 cm (12 in.) diameter by 10 cm (4 in.) wide smooth rolls. Both crushers had an adjustable crushing gap between the rolls, and each was driven by a single motor.

5.1.3. Idaho National Engineering Laboratory Tests

Crushing tests of unirradiated FSV carbide-coated fertile and fissile fuel particles were performed by Allied Chemical Corporation at Idaho National Engineering Laboratory (INEL) for the Energy Research and Development Administration (ERDA) using a double-roll crusher. This machine had 10 cm (4 in.) diameter by 3.8 cm (1.5 in.) wide smooth-faced rolls with an adjustable roll gap and a variable-speed single motor drive.

5.1.4. Test Results, Background Tests

Background 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 excessive unbroken particles.

5.1.5. Testing Information

Background 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 from background crusher tests at ORNL, INEL, or GA.

Design and operations personnel at GA, through meetings and design conferences, used the available background test data and information to develop a list of design requirements and a design criteria for a fuel particle crusher for use in the fuel-reprocessing pilot plant. This crusher is the reference fuel-particle crusher.

5.2. OPERATIONAL TESTS, REFERENCE CRUSHER

Test programs for the fuel-particle crusher called for experimental work to ascertain that the crusher achieved the design objectives.

Two fuel-particle crushers were built to the reference design and were tested crushing FSV fertile-fuel particles and both FSV and LHTGR fissile-fuel particles. One crusher was operated on line in the head-end system during sequential operations of the cold pilot plant.

5.2.1. FSV Fertile Particle Crushing (Ref. 2)

The double-roll, fixed-gap, fuel-particle crusher was tested for the ability to successfully process FSV fertile-fuel particles. Tests were performed on representative feed lots split from a single larger lot. The tests were arranged so that actual crusher performance could be compared with the performance requirements of the particle-crusher design criteria.

The tests were designed to determine (1) the crusher throughput rate and the relationship of throughput to roll speed; (2) the crusher power requirements during start-up, operation, and start-under-load conditions; (3) the percentage of uncrushed or unbroken fuel particles in the crusher product; and (4) the roll gap at which the product size distribution meets the 160 μm (0.0634 in.) requirement defined in the design criteria. Item 4 was the main objective of the initial tests.

5.2.2. FSV and LHTGR Fissile Particle Crushing (Ref. 2)

The pilot-plant experimental plan called for the reference crusher to successfully fracture the silicon-carbide coatings on the FSV and LHTGR fissile-fuel kernels. The same double-roll used to crush fertile particles was employed, but with different roll diameters. Testing involved establishing a nominal crushing roll gap to maximize crushing efficiency and to achieve the required particle size of 250 μm (0.0987 in.).

The relationship of the crusher roll rotating (running) torque versus the roll gap was studied to establish a correlation between the roller-bearing radial preloads and the roll-crushing gap. This study made necessary the development of a reliable and repeatable method for measuring the roll gap.

The second crusher was also tested for whether it met the design criteria during its processing of FSV and LHTGR fissile-fuel particles.

5.2.3. Test Results, FSV Fertile- and Fissile-Fuel Particles

The reference-design fuel-particle crushers, driven by 560 W (0.75 hp) and later by 746 W (1 hp) variable-speed, dc electric motors with a 40-to-1 speed reducer, demonstrated the capability of the double-roll crusher with a fixed crushing gap to successfully process FSV fertile- and both FSV and LHTGR fissile-fuel particles.

The test results were as follows:

	<u>FSV Fertile</u>	<u>FSV Fissile</u>	<u>LHTGR Fissile</u>
Throughput rate [kg/h (lb/hr)]	50 (110.23) at 25 rpm	80 (176.37) at 43 rpm	55 (121.25) at 36 rpm
Size distribution	See Fig. 3	See Fig. 4	See Fig. 5
Roll gap (% unbroken)	<1	<1	<1
Power, normal [W (hp)]	Not available; restarts under load	522 (0.699) at 43 rpm; restarts under load	250 (0.335) at 36 rpm; restarts under load

The study of bearing preload and roll torque versus the roll crushing gap established that preload (as measured by the amount of torque to rotate one roll with no crushing load) of ~ 0.26 m-kG (40 in.-lb) would produce a constant and consistent roll gap. Higher preloads reduced bearing life and increased the power requirements. Lighter bearing preloads did not adequately seat the bearings and permitted the rolls to displace under the crushing loads, resulting in an inconsistent roll gap and an increased amount of unbroken fuel particles.

The best method for measuring the roll-crushing gap was the use of 0.33 cm (0.13 in.) diameter Sn60 solid-core solder, which was manually roll-reduced by the rolls. Using solder in this manner introduced a load to the rolls which was similar to that encountered during particle crushing. Roll gap measurements by this method produced consistent and repeatable results.

A significant wear problem in the reference particle-crusher design became apparent upon completing the initial fertile-particle crusher tests and after processing approximately 150 kg (330.7 lb) of FSV fertile-fuel particles. This problem was evidenced by an increased amount of unbroken fuel particles in the crusher product.

Fig. 3. Fuel particle crusher product size distributions for various throughput rates

Fig. 4. Size distributions, crushed WAR particles

Fig. 5. Feed and product size distributions, FSV fissile particle crusher

The crusher was disassembled to determine the reason for this increase. No apparent wear on the roll-crushing surfaces or on the roll ends was found, and there was no evidence of spalling, gouging, or galling on any wearing surface. However, each side-body plate showed extensive erosion in the region opposite the crushing region at the ends of the roll pairs.

To abrogate this problem, the wear grooves were filled with various cemented carbides and hard ceramic materials applied by plasma spraying. These materials were rapidly eroded away during tests, as had been the hardened (R_C60) tool-steel side-body plates. The side bodies were next slotted by electrical discharge machining (EDM), and inserts of high-density cermets and solid ceramics were embedded in the slots. Each side plate contained a different candidate insert material for comparative evaluation. The greatest success was achieved with inserts of a boron-carbide solid ceramic. This ceramic is harder (2750 Knoop) than solid silicon carbide (2480 Knoop). Table 1 lists the various test insert materials used in the side-body plates and gives the test results obtained while crushing silicon-carbide-coated fuel particles.

5.2.4. Sequential Operations (Refs. 3 and 4)

One of the two fuel-particle crushers built to the reference design was used in the cold pilot plant for two sequential crush-and-burn operational tests. In the first sequential run, 20 LHTGR fuel elements (blocks) were crushed in the size-reduction system (UNIFRAME), and the graphite was burned off in the primary burner. The remaining fuel particles were classified, and a 49.3 kg (108.7 lb) fissile fraction of classified primary burner product was used as feed for the fuel-particle roll crusher.

In the second sequential run of the cold pilot plant, the fuel-particle roll crusher was fitted with a more powerful drive system to avoid the periodic inability to start under load and the stoppages from overload. This condition was averted in the initial sequential operation

TABLE 1
SIDE BODY WEAR DATA, FERTILE PARTICLE CRUSHER

Material	Source and Type	Hardness (a)		Abrasion Resistance (b)	Observed Wear	Crusher Throughput [kg(lb)]	Comments
		R _C	R _A				
Tool steel	AISI D2	57	79	13 to 14	Slot, 0.3 mm (0.012 in.) deep x 0.6 mm (0.025 in.) wide	150 (330.7)	As designed
Chromium oxide, plasma spray	Metco 136F, repair	74	89	Unknown	100% removed	60 (132.2)	No binder
Tungsten carbide, plasma spray	Metco 73F, repair	60	81	Unknown	>90% removed	60 (132.2)	Best plasma spray product: cobalt binder
Tungsten carbide, plasma spray	Metco 71VF, repair	53	78	Unknown	100% removed		
Tungsten carbide and chromium oxide, solid ceramic	Kennametal K703, insert	80	92	760	Slot, 0.1 mm (0.0044 in.) deep x 0.6 mm (0.055 in.) wide	150 (330.7)	Cobalt binder, best composite material
Tungsten carbide, solid ceramic	Kennametal K68, insert	>80	93	300	Slot, 0.2 mm (0.0073 in.) deep x 0.7 mm (0.028 in.) wide		
Boron carbide, solid ceramic	Norton Co. B ₄ C, insert	2750 Knoop (c)		Unknown (d)	Traces, (e) not measured	180 (396.8)	None

(a) From vendor data, except D2 tool steel, which was hardness tested.

(b) Abrasion resistance equals unity divided by volume loss with dry silica sand (Kennametal data).

(c) For comparison, solid tungsten carbide = 1880 Knoop and solid silicon carbide = 2480 Knoop.

(d) Material used in sand blast nozzles.

(e) Product continues to be acceptable after crushing.

by restricting the flow of feed to the crusher with an orifice. The crusher was also assembled with some improved bearing seals to permit study of the amount of product stream material entering the bearings and the resultant bearing wear.

A 46.5 kg (102.5 lb) portion of the classifier overhead fissile stream was used as feed to the fuel particle crusher, and crushing was started. Forty-four minutes after startup, the crusher stopped due to a tripped circuit breaker. The apparent average crushing rate to that time was ~ 1.0 kg/min (~ 0.45 lb/min). The roll speed throughout the crushing run was ~ 40 rpm. It was assumed that crushing had been completed, and a restart was not attempted. It was subsequently found that ~ 0.3 kg (~ 0.66 lb) of uncrushed feed material still remained in the system. The total product was 31.3 kg (69 lb) after burning. This product was found to contain 8.72% of unbroken particles, far exceeding the requirement of 1% maximum. Factors other than roll wear or side-body wear were contributing to this sharp increase in unbroken particles.

The large percentage of unbroken particles is hypothetically attributed to excessive bearing wear, due to inadequate bearing shielding from the crushed product and to manufacturing deficiencies of the crusher components. Prior to startup of the particle crusher, the crushing gap was 0.546 cm (0.0215 in.), and after the sequential run it was 0.597 cm (0.0235 in.). This large change could have resulted from improper bearing preload and seating procedures, allowing the rolls to displace during crushing operations.

5.2.5. Test Results, Sequential Operations

The fuel-particle crusher operated satisfactorily during the first sequential run and produced a burner feed product which was successfully burned in the secondary burner. The crushed and burned product contained less than the maximum permissible 1% unbroken fuel particles.

The results of the fuel-particle crushing during the second sequential run of the pilot plant pointed out the need for tighter manufacturing controls, improved bearing protection and preload methods, and an increase in crusher drive efficiency.

6. FACTORS LEADING TO IMPROVED DESIGN

The double-roll crusher with a fixed crushing gap and constant speed drive performed as expected during testing and met the design requirements. As a result of crusher operations, certain modifications and alterations to the design have been indicated:

1. Reduce manufacturing and assembly complexity and cost by using a new housing design.
2. Increase the wear life of the roll end side plates by selective hardening or other means.
3. Provide thermal expansion capability, simplify the bearing pre-loading, and assure improved reliability by using a modified bearing design.
4. Increase bearing protection by introducing improved bearing seal methods.
5. Assure restart capability when fully loaded and avert stalling under a rapidly applied full load by upgrading the drive system.
6. Extend roll wear life by altering the roll hardness, materials, or heat treatment.

Each of these topics was addressed during a complete design evaluation of the existing (reference) particle crusher to assess its suitability as a prototype to the HRRF. The fuel particle crusher was completely redesigned to reflect recommendations arising out of this design evaluation and the continuing operation of the crusher.

7. DESIGN DESCRIPTION, MARK 2 CRUSHER

7.1. CRUSHER MODULE

The design evaluation of the reference fuel-particle crusher module (Ref. 5) studied performance, cost, ease of implementing changes, and the impact of such changes on the current HRRF design. Feasible alternative designs were similarly evaluated. The prototype design (Mark 2), resulting from this and any subsequent evaluations, should be capable of performing all required functions at the lowest present cost when extrapolated over the life of the HRRF. The scope of the design evaluation identified numerous design features mandated by the basic process requirements or by the HRRF facilities requirements. These features included

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

Alternatives to reference crusher designs were assigned to each of the design features under review. Then the alternative designs were compared to reference designs using a simple ranking system. The attributes considered in the ranking comparisons were performance, reliability, maintenance, operability, and initial cost.

After evaluation of each of the five features and comparison of the reference design against proposed alternatives, an integrated design was recommended which combined the best features of the various designs. The integrated design was recommended as the proposed next-generation fuel-particle crusher, and with suitable remote interfaces, it represents an HRRF-compatible prototype.

7.2. CRUSHER DRIVE AND BEARINGS

Drives in the particle crushers were powered initially by dc electric motors to permit varying motor speeds and changing crushing rates, thus establishing the relationship between roll speed and crusher efficiency. From these tests, a single operating speed could be determined for particle crushing. Power calculations using then-known data were compared with prior test results and power demands on similar equipment, and it appeared that a 560 W (0.75 hp) drive motor would be satisfactory. Due to the many uncertainties in the calculations, however, provisions were made to permit upgrading the drive to 746 W (1 hp) by simply replacing the 560 W (0.75 hp) motor with the more powerful unit. This was subsequently done.

Early in the testing, the crusher drive motor created problems by stalling. The cause was attributed to crusher manufacturing inaccuracies and to roller bearing overheating, resulting from improper lubrication and bearing-grease contamination from the crushed-product dust. The crusher bearings were submitted to the manufacturer for evaluation, and grease samples were extracted from each bearing for analysis of contaminants, i.e., metallic particles, silicon carbide, and similar residuals from the product stream.

Finely divided foreign material, including silicon carbide, was found in varying amounts in the bearing grease. Thus, there existed a potential for accelerated bearing wear, overheating, and eventual failure. The bearing manufacturer confirmed that apparently the silicon-carbide dust got into the bearings, causing excessive wear. This, coupled with an unnecessarily high bearing preload, contributed to the bearing overheating and the drive motor overloading.

The bearing manufacturer recommended improving the sealing of the bearings, to exclude the dust and foreign materials, and reducing the bearing preload.

The drive requirements for the particle crusher were recalculated to include new and conservative torque values for the passive particle load, the crushing work, and active maximum bearing preloads. Since the particle crusher operates at a single speed, a variable-speed drive was not needed, and the drive was changed to an ac squirrel-cage induction motor (NEMA, Class B). With constant-speed roll operation, an ac motor is a better drive choice, since it operates best at a single speed. The standard squirrel-cage induction motor (NEMA, Class B) has operating characteristics that are attractive to the crusher drive. These motors will deliver two to two and one-half times the operating torque at start for start-under-load conditions, and the torque rises sharply with modest decreases in speed from full operating speed (when the load is applied, the speed decreases, and the stall torque rises). The ac motors are also smaller and lighter than their dc counterparts and have simplified electrical controls. Recalculation of the motor drive requirements for the Mark 2 particle crusher indicated the need for a 1492 W (2 hp) drive at the roll speed of 40 rpm.

7.3. IMPROVED DESIGN DESCRIPTION

The Mark 2 fuel particle crusher assembly is shown on drawings 5211012, 5211013, 5211014, and 5200024. This design maintains the fixed (nonadjustable) gap design of the earlier GA crushers. The housing is of a two-piece construction, which will substantially reduce manufacturing complexity and unit cost.

The Mark 2 particle crusher is not intended as a remotely maintainable unit in a radioactive facility. At the end of its operating life or for maintenance purposes, the crusher is to be remotely removed from the system and replaced as a unit.

The Mark 2 crusher drive is a single-speed, ac electric motor driving through a gear reducer and a single pair of open, steel spur gears. One drive gear powers the counter-rotating roll gears.

7.3.1. Bearing Design

The bearings for the Mark 2 crusher are single-row, self-aligning, spherical roller bearings with integral dust seals. The bearings are mounted on tapered shaft adapter sleeves for preload adjustments. One bearing in each roll set has the capability of accommodating axial thermal expansion during crusher operation. Each bearing is additionally protected by a spring-loaded face seal located in the roll and by a metallic spring membrane seal located between the inner and the outer bearing races on the dust side. Thus, each bearing is afforded triple protection from the abrasive dust generated by fuel-particle crushing.

Preloading of individual bearings is accomplished by rotating the adjusting lock nut, which is mounted on each tapered shaft adapter sleeve. This drives the tapered inner race of the spherical bearing up the tapered sleeve, reducing the roller radial clearances and ultimately introducing the desired preload into the bearing. Each bearing is independently preloaded in this fashion without interaction with the other bearings.

7.3.2. Crusher Module Housing

The crusher housing is a two-piece mild-steel unit, which receives its final precision machining as one piece after both halves have been face machined, bolted, and pinned together. This construction permits the use of conventional and readily available machine tools and simplifies the final assembly. The final machining of the large bores and the critical internal surfaces is much simplified with the two-piece construction, compared to the five-piece housing of the reference design.

The internal machining of the particle feed tube and the crushing cavity for the Mark 2 crusher create features which will divert particles from the roll ends and which are intended to help minimize the high wear in the housing at the roll ends.

The localized wear in the housing at the roll-end positions, discovered in tests, is accommodated by embedding a hard-ceramic insert into the appropriate housing location. General roll-to-housing wear is minimized by hard-chromium-plating the inner face of each housing. Initially, only one insert will be implanted so that wear observations may be made during proof testing. Later, if desired, the insert may be applied to the other housing half.

The Mark 2 particle crusher, shown in drawing 5211012, illustrates the housing constructed of two solid-steel pieces machined and welded to dimension. In a production situation, the two halves would be identically cored castings with a longitudinal parting plane.

The top and bottom faces of the roll housing are machined to interface with a flange on the particle feed tube and to mount directly onto the feed hopper of the secondary burner. The interfacing surfaces and the two halves of the housing are sealed with Grafoil, an all-graphite tape.

7.3.3. Crushing Rolls

Tests showed that there were no definable trends in the wear of the crushing rolls from crushing the silicon-carbide-coated fuel particles. There were also no identifiable differences in the performance of the carburized and case-hardened AISI 1018 steel rolls, as compared with the hardened AISI 4340 steel rolls. Therefore, the crushing rolls for the Mark 2 crusher are made of a standard carburizing-grade carbon steel, AISI 8620, with a case hardness of R_C 61.

8. SUMMARY OF THE MARK 2 DESIGN

The improved fuel-particle crusher design was influenced by operating similar crushers on silicon-carbide-coated fuel particles to expose the inner carbon coatings for fluidized-bed burning. Design improvements will permit the crusher to operate with high reliability, to have extended wear life, and to be manufactured with reasonable cost effectiveness. The Mark 2 design is considered to be a second generation design of the fuel particle crusher, and with remote interface, it represents an HRRF compatible prototype.

9. FUTURE WORK

A fuel-particle crusher will be manufactured to the Mark 2 design, and a new test program will be devised to proof and operationally test this second-generation fuel-particle crusher.

ACKNOWLEDGEMENTS

The author wishes to thank J. B. Strand and W. S. Rickman for their participation in the testing and operation of the reference crushers and for their input into the design of the Mark 2 fuel particle crusher. A special thank you also to the staff technicians in the Operations Branch of the GA Recycle Development Department, who participated in the testing of the reference crushers. The Recycle Development Department design drafting group must be acknowledged for their fine efforts and assistance in the preparation of the Mark 2 design.

REFERENCES

1. Baer, J. W., et al., "Interim Design Report: Fuel Particle Crushing," DOE Report GA-A14675, General Atomic Company, November 1977.
2. Baer, J. W., and J. B. Strand, "Interim Development Report: Fuel Particle Crushing," DOE Report GA-A15073, General Atomic Company, September 1978.
3. "The General Atomic HTGR Fuel Reprocessing Pilot Plant: Results of Initial Sequential Equipment Operation," DOE Report GA-A15081, General Atomic Company, September 1978.
4. "The General Atomic HTGR Fuel Reprocessing Pilot Plant: Results of Second Sequential Equipment Operation," General Atomic Company Report GA-A15343, to be published.
5. Johanson, N. W., "HTGR Fuel Particle Crusher Design Evaluation," DOE Report GA-A14957, General Atomic Company, October 1978.

APPENDIX A
ENGINEERING DRAWINGS

5211012	Particle Crusher Assembly - Model 2
5211013	Particle Crusher - Details Model 2
5211014	Particle Crusher - Housing Assembly Model 2
5200024	General Assembly Particle Crusher

- NOTES:
1. DIMENSIONING & TOLERANCING PER ANSI Y14.5
 2. REMOVE ALL BURRS & SHARP EDGES
 3. HARDEN 3.9800 DIA ROLL SURFACE TO PRODUCE A MIN. 0.60 THK. HARDENED SKIN TO EC 61 - DOUBLE QUENCH & TEMPER FOR MAXIMUM CORE DUCTILITY
 4. SOURCE: OHIO GEAR, LIBERTY, S.C.
 5. SOURCE: MCGILL MFG. CO., INC. BEARING DIV. VALPARAISO, IND.

ITEM	PART NO.	DESCRIPTION	MATL.
4	SNW 10	TAPERED ADAPTER SLEEVE ASSY	5
3	-3	BEARING RETAINER	STEEL A151 1010-1080
2	TST 892	SPUR GEAR	4
1	-1	ROLLER	ALLOY STEEL A151-0620

REV.	DATE	BY	CHK.	DES.	APP.	APP.
1	12/1/75	SPR	ECO	COG	BE	
2	12/1/75	TR	LIM	IMP

- 1 26 LOOSELY HOPPER ASSY

GENERAL ASSY.	GENERAL ATOMIC CORPORATION
---------------	---

PARTICLE CRUSHER		COMPANY	
		SAN DIEGO, CALIFORNIA	
		DRAWING NUMBER	REV.

sk	520024	4
----	--------	---

14/1