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LABORATORY DEVELOPMENT OF THE GRIND-LEACH PROCESS FOR THE H.T.G.C.R. FUEL CYCLE
PART III. COMMINUTION OF BERYLLIA MATRIX FUELS

by

M.G. BAILLIE
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October 1966

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ABSTRACT

A comminution process has been studied for the preparation of fuel from an H.T.G.C.R. pebble bed reactor for leaching prior to purification and recycle of its valuable constituents.

The selection of suitable equipment for this step is discussed, and experimental work to demonstrate a three-stage vibratory grinding circuit on a small scale, using inactive fuel, is described. It has been shown that, for inactive fuel, a ground product having characteristics which make it suitable for feed material to the selective leaching step can be produced by this technique.

PREFACE

This report is Part III of a series of reports:

> Laboratory Development of the Grind–Leach Process for the H.T.G.C.R. Fuel Cycle.

Other reports issued in this series are:

> Part I. Dissolution of urania–thoria fuel particles in nitric acid solutions, by M.S. Farrell and S.R. Isaacs. AAEC/E143.
>
> Part II. Dissolution of beryllia in nitric acid solutions, by M.S. Farrell, S.R. Isaacs, and M.E. Shying. AAEC/E154.

Companion series deal with:

> Development of Solvent Extraction Processes for the H.T.G.C.R. Fuel Cycle.
>
> > Part I. Design of a flowsheet for the recovery of actinides, by M.G. Baillie and R.K. Ryan. AAEC/E139.

and

> Economics of the H.T.G.C.R. Fuel Cycle.

CONTENTS

1. INTRODUCTION

The Australian Atomic Energy Commission has recently studied the feasibility of an advanced, high temperature, gas-cooled reactor. The proposed wholly ceramic fuel consists of a mixture of fissile and fertile oxides dispersed in a matrix of beryllium oxide moderator as particles 150–200 microns in diameter (Roberts 1964). Recovery of the valuable actinides and beryllia from such a fuel is difficult because of the small concentration of actinides present and because of the chemical inertness and refractory nature of the beryllia (Cairns 1964). To allow aqueous methods of recovery to be used, and to permit recovery of the valuable moderator, it is necessary to adopt a grind-leach technique for the head end step in the process.

This report is one of a series describing the development of an aqueous reprocessing flowsheet for beryllia-based fuels, and is concerned with the feasibility of a comminution process for reducing oxide fuel elements to a size suitable for leaching. The leaching process envisaged is a two-stage operation involving the leaching of the bulk of the fissile/fertile fuel components with nitric acid, followed by dissolution of the residual beryllia in sulphuric acid. Development of the leaching process is described in other reports of this series (Farrell and Isaacs 1965; Farrell, Isaacs, and Shying 1966; Shying, Lee, and Farrell 1966).

As the first part of this study, it was necessary to consider qualitatively the important requirements of a comminution step and to use this assessment in the preliminary selection of equipment suited to the process. This part of the study (discussed in Section 2) provided a tentative equipment flowsheet for practical study.

The second part of the study was an assessment of the feasibility of the process using small-scale equipment and a simulated flowsheet. The results of this investigation (set out in Section 3) enabled an assessment of the probable physical properties of ground fuel to be made for use in concurrent design studies. These properties have a marked effect on the selectivity of the two-stage leaching process.

2. DESIGN ASPECTS OF A COMMINUTION FLOWSHEET

2.1 Performance Criteria

In order to provide the most suitable feed material for the subsequent leaching step, the following characteristics are desirable in the ground fuel:

(i) A sufficiently fine product to ensure that leaching takes place in an acceptable time.

(ii) High exposure of fissile-fertile particles in the ground fuel to facilitate selective leaching.

(iii) If possible, selective grinding of the fissile/fertile content to increase selectivity of leaching.

(iv) A narrow reproducible size range with a low beryllia fines content.

Complete exposure of all fissile-fertile particles would be expected when the fuel had been ground to a size equivalent to the fissile-fertile particle size of 150–200 microns, which corresponds to a sieve size range of 72–100 B.S.S. A maximum ground fuel size of 100 B.S.S. was therefore set for initial grinding studies.

Later Shying, Lee, and Farrell (1966) showed that fuel, ground to a larger limiting aperture, still exhibits a high effective chemical exposure. This led to the adoption of 52 B.S.S. (300 microns) as the limiting sieve size for all multi-stage grinding work, since the increased handling difficulties presented by a very fine powder made it undesirable to grind any finer than necessary.

Taggart (1945) has pointed out that, for an average ore, grinding in a closed-circuit ball mill under normal operating conditions results in about 50 per cent. by weight of the product being less than 10 per cent. of the limiting screen size. Thus with a limit of 100 B.S.S. (152 microns), 50 per cent. of the ground product would pass 15 microns. The wide size range of this product would make a selective leaching process ineffective owing to the dissolution of a high percentage of beryllia under these conditions (Farrell, Isaacs, and Shying 1966). Reduction of this fines fraction is usually achieved in a closed-circuit comminution process by operating with a high circulating load and a low mill residence time. This technique is aimed at approaching as closely as possible to the single breakage or "π breakage" theoretical model in which a proportion (π) of the particles is broken once only in each pass through the mill (Callcot and Lynch 1964). A further reduction in over-grinding can be obtained if the maximum impact energy used to achieve breakage can be controlled to a value equivalent to the minimum energy for breakage of the largest particles present.

The relatively hard nature of beryllia suggested that some degree of preferential grinding of the fissile-fertile particles could be expected, especially under conditions favourable to low overall fines formation. This would achieve the desired result of an increased concentration of fissile and fertile materials in the finer fractions of the ground product, but the extent to which this might occur could not be predicted.

In addition to the above requirements, which are imposed by the needs of the leaching step, there are several general requirements set by the nature of the overall processing plant of which the comminution equipment forms a relatively minor part. The equipment must be completely sealed, dust-tight, and capable of remote operation for extended periods in fields of high-intensity radiation with little or no maintenance. The equipment, including solids handling and storage facilities, should be compact, using a minimum of both floor area and cell space to reduce the cost of the shielded facility to a minimum.

2.2 Selection of Equipment

The size-reduction operation entails the breakage of 2.5 cm diameter fuel pebbles (Roberts 1964) to less than 300 microns, that is, a reduction ratio of about 100. Because of the relative hardness of beryllia and the desired minimization of fines, a multiple-stage size-reduction step is necessary.

2.2.1 Crushing

The crushing stage involves reduction to approximately 3 mm. This operation could be performed by two stages of jaw or gyratory crushers each having a reduction ratio of approximately three. The choice of crusher types depends mainly on the throughput to be handled, but for the very low capacities required in this application, the smallest gyratory crusher available would be somewhat oversized. The smallest jaw crusher, on the other hand, would have a suitable capacity for this purpose. Opinion is divided on the problem of maintenance for each crusher type (Taggart 1945; McCabe and Smith 1956), but the remote replacement of wear plates appears to be simpler for a jaw crusher. For these reasons, and because less head room is necessary, jaw crushers are favoured for both primary and secondary crushing of fuel pebbles. It must be pointed out, however, that final selection of the equipment for this purpose cannot be made until tests have been made with irradiated fuel, and it is quite possible that special crushing equipment may be designed for this application.

2.2.2 Grinding

The grinding plant is required to reduce -3 mm material to -52 B.S.S.(295 microns). This reduction ratio is within the range attainable by a number of types of grinding device, all of which would suffer from the disadvantage of considerable wear on the grinding surfaces due to the highly abrasive nature of the fuel. In a ball mill, however, this problem can be overcome by addition of grinding media as required during operation of the mill.

A conventional ball mill operating continuously in closed circuit with a dry classifier would have to be equipped with dust-tight rotary seals at each trunnion. These seals, operating under highly abrasive conditions, would be difficult to design for extended operation without maintenance. The use of a vibrating ball mill with flexible connections to adjoining items of equipment provides a solution to this problem. However, in this case, the low maintenance objective can only be attained if reliable all-metallic flexible connectors can be designed to replace the radiation-affected synthetic couplings normally used for this purpose.

Consideration of these factors points to the selection of vibrating ball mills for all stages in the proposed grinding circuit.

2.2.3 Associated operations

The operating requirements for a product having a narrow size range are best fulfilled by stage grinding of sized fractions. Such a grinding circuit requires a classifying device capable of producing a number of closely sized fractions on a continuous basis; this criterion is adequately met by several commercial multiple gyrating screens with peripheral discharge of oversize material.

Where transfer of powdered fuel cannot be achieved by gravity alone, a system of feeders, conveyors, and elevators is necessary. For reasons of remote control, simple maintenance, dust free operation, and reliability, fully enclosed vibrating equipment was selected for each of these purposes.

2.3 Design of a Suitable Flowsheet

The basic equipment types selected in Section 2.2 were integrated into a basic equipment flowsheet suitable for testing experimentally. Figure 1 shows an arrangement incorporating a three-stage grinding circuit. Each vibrating ball mill is required to provide a reduction ratio of only two. This condition approximates to the theoretical mechanism of single particle breakage required for no-fines grinding if all particles are broken to half their original size in one pass through the mill. Although this mechanism is not followed closely in practice it serves as a basis for establishing an initial flowsheet for experimental testing.

Following establishment of the feasibility of the unit operations involved in this initial flowsheet no further small-scale work is warranted. Optimisation of the operating parameters and assessment of the reliability of this type of plant can only be achieved by full-scale testing using fully irradiated fuel. Considerable developmental work will also be necessary to ensure the operability of the integrated crushing, grinding, and classifying equipment.

3. FLOWSHEET FEASIBILITY STUDIES

The object of this investigation was to establish the feasibility of a comminution flowsheet of the type outlined in Section 2. Small-scale equipment was chosen for this initial work, although it is appreciated that some difficulty will be experienced in scaling up to larger units. However, considerable flexibility exists with this type of equipment and it is reasonable to assume that conditions can be selected so as to achieve a similar product from larger equipment. This assumption enables the experimental product to be used for leaching studies as a representative sample of ground fuel.

3.1 Experimental

3.1.1 Crushing

In all comminution runs reported here, primary and secondary crushing to a size 100 per cent. -0.125 in. was achieved by hand breakage methods. Fuel samples in the form of cylinders 1.125 in. diameter by 2.0 in. long were broken up in a 1.5 in. diameter cylindrical steel mortar by driving a solid steel pestle against the fuel pellet. Frequent removal of crushed product on a 5 B.S.S. screen was necessary, to keep the proportion of fines to a minimum and to simulate more closely the operation of a jaw crusher.

The effect of any variations between the size distributions of crushed product produced by hand breakage and by jaw crushing is not significant when stage grinding is used. However, comparison of the products from hand breakage and two-stage jaw crushing using alumina showed that the percentage of -100 B.S.S. material after crushing was the same (4.7 - 6.1 per cent.) for both methods.

3.1.2 Semi-batch grinding

A technique was developed to simulate continuous grinding conditions in a batch mill. In runs P-1 and P-2 a Griffin vibrating laboratory ball mill (0.5 l capacity) was charged with crushed feed and operated intermittently for about 30 minutes. After each 3 minutes of grinding the mill was emptied, the contents split on a 100 B.S.S. sieve, and the oversize material returned to the mill for further grinding.

In run P-3 the procedure was modified to simulate three-stage grinding by splitting on 52, 22, and 12 B.S.S. screens after each grind. Initially, the +12 B.S.S. fraction was returned to the mill each time until the output of -52 B.S.S. product from a grinding period fell below 3 per cent. of the total feed. The -12 +22 B.S.S. fractions collected up to this point were then combined with the +12 B.S.S. fraction and grinding was continued as before but splitting on 52 and 22 B.S.S. sieves each time.

When the 3 per cent. product point was reached once more, the 22 B.S.S. sieve was discarded and all oversize material from the 52 B.S.S. sieve was returned to the mill. Grinding was continued until the output of product fell to 4 per cent. of the initial feed, when the run was terminated.

After each run the product material was examined by sieve analysis and each size range was analysed for thorium content by a colorimetric technique.

3.1.3 Continuous grinding

As a result of the preliminary work on semi-batch grinding, a new vibrating mill was constructed having a stainless steel pot of 0.75 l capacity. This mill was designed for continuous operation and fitted with an outlet grate in the form of a restriction plate with three groups of different sized holes, any group of which could be used as the outlet grate by rotation of an external knob (see Figure 2). A motor-driven eccentric weight caused the mill to gyrate with an amplitude of 0.25 in. at 1440 vibrations per minute.

Operation of this mill in closed circuit as a simulated three-stage grinder required equipment for separation of the mill output into four size fractions. This was achieved by adapting a standard Russell gyratory laboratory sieving machine, as shown in Figure 3, to carry three modified 8-inch diameter sieves fitted with overflow spouts. This apparatus was fed by a 1.5 in. diameter star feeder of conventional design which delivered crushed material at a uniform rate to the top sieve. Because of the toxic nature of beryllia dust, the whole apparatus was housed in a glove box under a negative pressure of 2 inches water gauge.

The equipment was then set up as shown in Figure 3 so as to feed oversize material from the top sieve (14 B.S.S.) to the mill. The mill outlet restriction plate was set to 0.125 in. holes and feed to the sieves was commenced. As the mill product appeared it was collected in a receiver and transferred by hand to the sieve feeder to keep the cycle operating.

When approximately 90 per cent. of the feed material had been collected in the product and intermediate fraction receivers, the flexible tubes carrying sieve overflow fractions were re-arranged so as to feed oversize material from both the top and second sieves (14 and 22 B.S.S.) to the mill. At the same time the +22 -14 B.S.S. fraction collected up to this point was added to the sieve feed hopper and the mill outlet plate was rotated to bring 0.063 in. holes into position.

Once again the system was operated until approximately 90 per cent. of the initial feed could be accounted for in the product and intermediate fraction receivers. The third sieve oversize material (+52 -22 B.S.S.) was then fed to the mill together with the remaining larger fractions, and the mill outlet restriction plate was set to 0.030 in. holes. The apparatus was then run until no further output appeared in the mill receiver.

After each run the product material was examined by sieve analysis only, except for run I.G.-5, where colorimetric analysis of the thorium in each sieve fraction was undertaken.

3.2 Results

The feed material for all eight runs in this series was a pressed-and-sintered dispersion of urania-thoria particles in beryllia, having a composition corresponding to UO_2:ThO_2:BeO = 1:20:2000 mole ratio.

Results for all runs are summarised in Table 1.

The sieve analyses on the products of runs P-1 to P-3 were performed dry. Some difficulty was experienced with balling and caking on the 200 and 300 B.S.S. sieves and this could have affected the accuracy of the last three fractions in these tests. As a result of this experience in preliminary work, the final runs I.G.-3, I.G.-4, and I.G.-5 were wet split on the 200 and 300 B.S.S. sieves using A.R. carbon tetrachloride as a wash liquor.

The overall material balances given in the table include all operations from initial crushing to sieve analysis. A comparison of runs I.G.-1 and I.G.-2 indicated that fine material had been held up in the grinding circuit and carried over from the first to the second run. For this reason sizing and material balance figures for the combined runs are given in Table 1.

All thorium balances are based upon the weighed-in components used in the manufacture of the original fuel pellets because of the difficulties experienced in obtaining a suitable sample for analysis from either massive or ground fuel.

The product size distributions for the I.G.-series were plotted according to the Gaudin-Schuhmann equation (Figure 5), and the slopes (distribution function) for each run are listed in Table 1.

The throughput of this particular set of equipment was variable, depending on the total quantity of feed to be ground. The average rate over the final run was 20 grams per hour using a feed of 364 grams. However, the maximum feed loading during this run was estimated to be 5 per cent. of mill volume, which almost filled the voids in the 15 per cent. of mill volume occupied by the pebble load. This feed-to-media ratio was normal but the hold-up of feed in the mill was very low at all times.

3.3 Discussion

3.3.1 Stage grinding

The large fines fraction (over 40 per cent.) produced in runs P-1 and P-2 can be attributed to two main factors. In the first place the high density grinding media (cast iron) used in these runs caused multiple breakage of particles rather than simple breakage. A characteristic of this type of grinding is always excessive production of fines. More important, however, was the use of a single stage grinding technique, compared with the three-stage method used in all later runs. When operated on a multi-stage basis, the mill was fed with particles of a relatively narrow size range. Breakage of a particle under these conditions always resulted in products smaller than the original size range and most of these were removed either by sieving (run P-3) or via the mill outlet grate (all I.G.-series) before further significant size reduction could take place. This technique closely approaches the π-breakage model mentioned earlier but no attempt has been made at this stage to apply the associated matrix-analysis techniques to the data collected. It is intended, however, that any further work which is done using fully irradiated fuel will be conducted with a view to determining a suitable breakage model for the application of this type of analysis.

Although it was possible to limit the impact energy of the grinding media in the mills used by controlling the amplitude of vibration, no attempt was made to optimise conditions for minimum fines during each of the three grinding stages used. In actual operation of a flowsheet such as Figure 1 it would be necessary for each of the three separate mills to be optimised for the particle size of its particular feed.

3.3.2 Differential grinding

The operation of ball and rod mills to produce preferential grinding of a soft component in a hard ore is well known in ore dressing practice. Such operations use a variety of techniques to ensure that the material concerned is given a very light grind and the undersize material is removed continuously from the circuit.

In this work attention was given to the design and operation of the mill to achieve light grinding for another reason, namely limited fines production, and it is not surprising that the relatively soft actinide oxides were found in increased concentrations in the finer product sizes. Increases in thorium concentration in the -300 B.S.S. fraction over that in the feed ranged from 32 to 88 per cent., a result which favours the selective leaching process.

Observation of the grinding chamber through a transparent end plate during early testing revealed that the movement of grinding media was characterised by long free paths between collisions, as would be expected from consideration of the very low mill loading used in these tests. This effect would be expected to produce far less breakage by scrubbing or scuffing actions than is experienced in vibrating and rotating ball mills operating at more normal loading ratios. This condition is of interest as it is the latter grinding mechanisms that are usually sought in practice to achieve differential grinding. Some scope obviously exists for future investigations into the feasibility of a process utilising coarse and fine crushing followed by an attrition, rather than a grinding process. By this means it may be possible to achieve very high liberation of fissile and fertile components from the matrix.

3.3.3 Product characteristics

The experimental work carried out in this study has been mainly concerned with the feasibility of producing ground fuel with a narrow size range in comminution equipment of conventional design. Optimisation of this process has been left for future studies.

Figure 4 summarises the product size distributions obtained from I.G.-series runs. Although run I.G.-4 gave the lowest fines fraction it also gave the highest coarse fraction, which could result in inefficient leaching due to locked fuel particles in the coarse grains. Examination of the results on this basis indicates the best run to be I.G.-5, which used the highest feed rate of the series. However it is difficult to estimate the effect of random variations in materials and process conditions over the small number of runs completed.

Based on these results it can be said that the production of ground fuel having 100 per cent. passing 295 microns and less than 20 per cent. passing 53 microns has been demonstrated for a feed material based on 150 to 200 micron fuel particles in beryllia at a concentration given by the mole ratio UO_2:ThO_2:BeO = 1:20:2000. This compares with Taggart's (1945) estimate of 65 per cent. passing 53 microns for a normal ground product having the same upper size limit.

3.3.4 Production rate

No estimation of possible rates of throughput can be made from the data presented. Because initial surveys indicated that impact fracture would be necessary, the mill loadings were kept very low to enable adequate pebble movement. Scale-up on the basis of a direct dependence of rate on mill volume is not possible since the actual optimum loadings have not yet been determined.

A further difficulty exists in that the mills were run on a decreasing load because the method of conducting the tests was essentially batch-wise. The actual rate of production of -52 B.S.S. product material followed three successive exponential-type curves corresponding to the three stages of size reduction.

Mill throughput also depends largely on the efficiency with which undersize material is removed from the grinding chamber. The simple restriction plate used on the experimental model was adequate for the limited mill loadings encountered in this work but much greater capacity would be needed to cope with the product from a more conventional loading. The last run (I.G.-5) gave the highest feed loadings of the series and an increase was noticeable in the fines fraction compared with the previous run. This may have been caused by over-loading of the restriction plate used for removing product. Inefficient product removal results in multiple breakage of particles and consequent unwanted fines production.

3.3.5 Size distribution

The sieve analyses of products obtained from the I.G.-series of runs were compared by standard distribution correlations, but acceptable agreement could be obtained only for the Gaudin-Schuhmann distribution equation (Gaudin 1939):

$$Y = 100 \left(\frac{x}{k}\right)^m ,$$

where Y = cumulative weight per cent. passing size x

m = distribution function

k = size modulus.

Although the basis for this equation is empirical it has a wide application in the mineral processing industry. Figure 5 is a plot of log Y versus log x for the runs considered. Results from runs I.G.-3, I.G.-4, and I.G.-5 fit reasonably to straight lines but the combined results from runs I.G.-1 and I.G.-2 show a marked change of slope at 150 microns. During the combined runs only the 0.125 in. and 0.063 in. grate openings were used on the mill outlet and this may have caused the altered size distribution by producing an increase in the relative weight of the finer fractions. This would be consistent with the theory that overgrinding resulted from attempts to handle a wide range of particle sizes in the mill at one time. This correlation is useful for extrapolation into the sub-sieve (-53 micron) sizes. Approximate estimates can be made of the particle size distribution down to about one micron particles by assuming a Gaudin-Schuhmann slope (m) of unity and a size modulus (k) equal to the limiting sieve aperture for the grinding process (300 microns in Figure 5).

3.3.6 Future work

Further work on comminution of beryllia fuels can provide useful results only if carried out on full-scale equipment, because of the difficulties encountered in scale-up from small units of this type. Further development of this comminution flowsheet must therefore involve full-scale inactive unit operations development, integrated inactive flowsheet testing, and finally a full process demonstration using fully irradiated fuel material.

4. CONCLUSIONS

(i) A comminution flowsheet has been proposed to reduce oxide fuel elements to a powder suitable for selective leaching.

(ii) Experimental examination of three-stage continuous grinding in a vibrating ball mill has established its feasibility.

(iii) The experimental equipment proved capable of producing ground fuel below 300 microns in size with less than 20 per cent. by weight of the total product in the fraction below 53 microns.

(iv) Owing to preferential grinding of the fuel particles, the sub-sieve (-53 microns) fraction was enriched in fissile/fertile content by from 30 per cent. to 90 per cent. compared with the composition of the initial fuel.

5. ACKNOWLEDGEMENTS

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TABLE 1

RESULTS OF INACTIVE GRINDING RUNS

Run No.	Fissile/ Fertile Particle Size (microns)	Fuel Bulk Density (g/cm³)	Batch Size (g)	Type of Grinding Operation	No. and Type of Grinding Media (spheres)	Size Analysis of Product (wt.%)							Thorium Analysis of Product (wt.% Th)							Overall Material Balance (%)	Overall Thorium Balance (%)	Dist. Function (m)
						+52 BSS	−52 +72 BSS	−72 +100 BSS	−100 +150 BSS	−150 +200 BSS	−200 +300 BSS	−300 BSS	+52 BSS	−52 +72 BSS	−72 +100 BSS	−100 +150 BSS	−150 +200 BSS	−200 +300 BSS	−300 BSS			
P–1	76–105	3.04	73.5	Semi–batch single–stage	14 x 1" cast iron	0	0.7	5.3	27.4	15.0	6.0	45.6	0	2.76	3.44	4.84	10.1	13.7	11.0	102.4	106.2	0.87
P–2	76–105	3.06	73.9	Semi–batch single–stage	22 x ½" cast iron 22 x ¾" cast iron	0	0	1.4	32.7	15.1	8.5	42.3	0	0	5.34	5.60	8.06	10.2	13.0	101.0	113.5	0.96
P–3	125–177	2.93	73.9	Semi–batch three–stage	30 x ¾" alumina	4.1	29.4	19.5	14.1	8.8	4.1	20.0	6.38	6.70	6.69	6.11	7.99	9.14	15.7	100.1	103.1	1.03
I.G. –1	177–211	2.99	147.2	Continuous three–stage	12 x ⅞" beryllia	0	33.3	21.2	12.7	6.5	7.2	19.1	Not analysed							95.9	n.a.	0.82 to 1.19
I.G. –2	125–177	3.02	148.8	Continuous three–stage	12 x ⅞" beryllia																	
I.G. –3	152–211	3.07	147.5	Continuous three–stage	12 x ⅞" beryllia	0	30.7	20.8	12.9	6.3	9.8	19.5	Not analysed							98.8	n.a.	0.97
I.G. –4	152–211	3.07	295.2	Continuous three–stage	12 x ⅞" beryllia	0	35.5	22.0	13.2	9.7	4.9	14.7	Not analysed							98.6	n.a.	1.14
I.G. –5	152–211	3.02	364.0	Continuous three–stage	12 x ⅞" beryllia	0.8	23.6	18.9	18.7	10.0	7.4	20.6	7.23	5.78	6.39	6.70	7.01	8.86	11.5	101.2	95.4	0.92

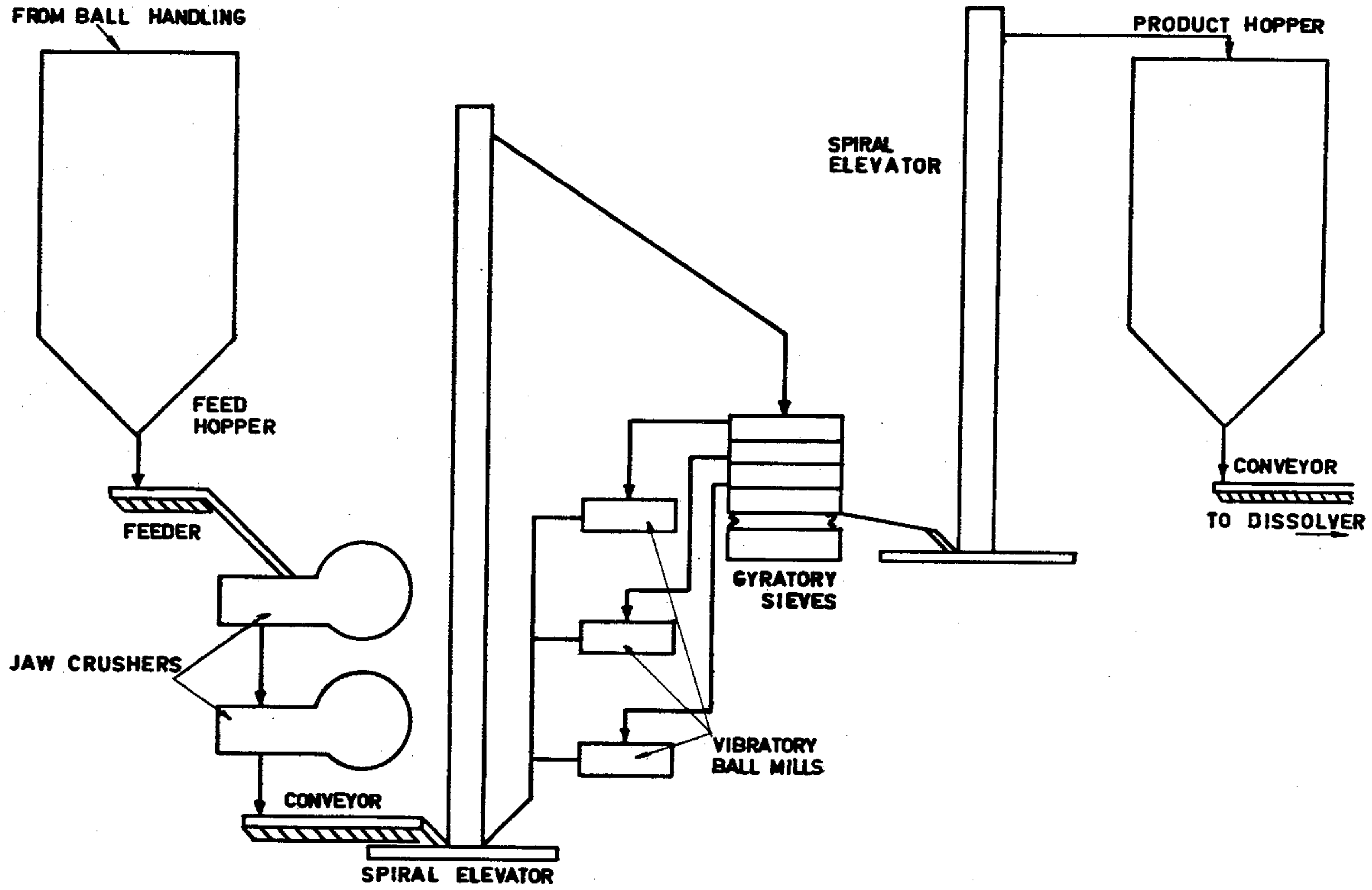

FIGURE 1. COMMINUTION EQUIPMENT FLOWSHEET FOR H.T.G.C.R. FUELS

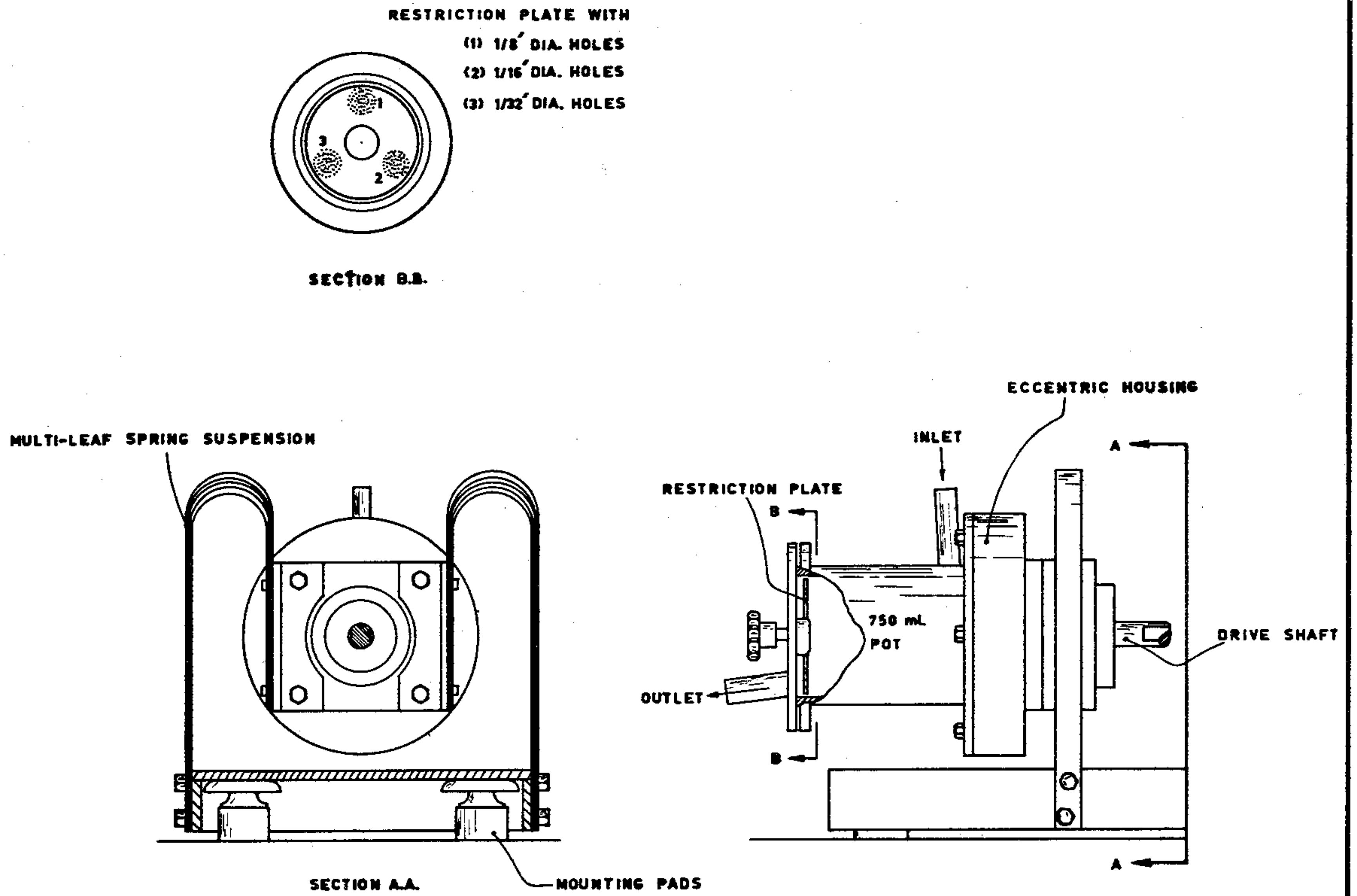

FIGURE 2. DETAILS OF VIBRATORY BALL MILL

RTCAREY

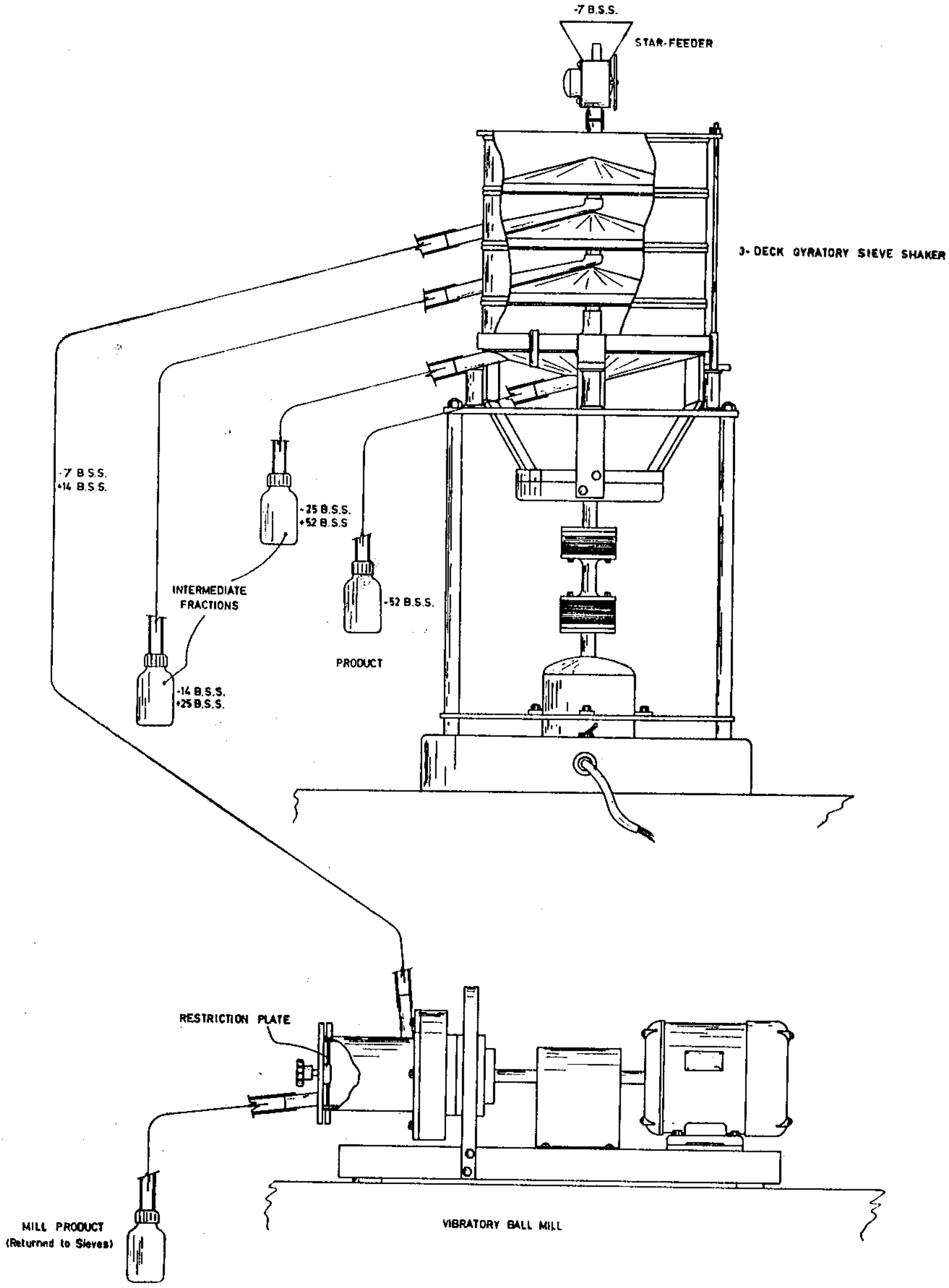

FIGURE 3. INACTIVE EXPERIMENTAL GRINDING RIG
FOR SIMULATION OF CLOSED CIRCUIT, MULTI-STAGE GRINDING OF BeO BASED H.T.G.C.R. FUELS

RT CAREY

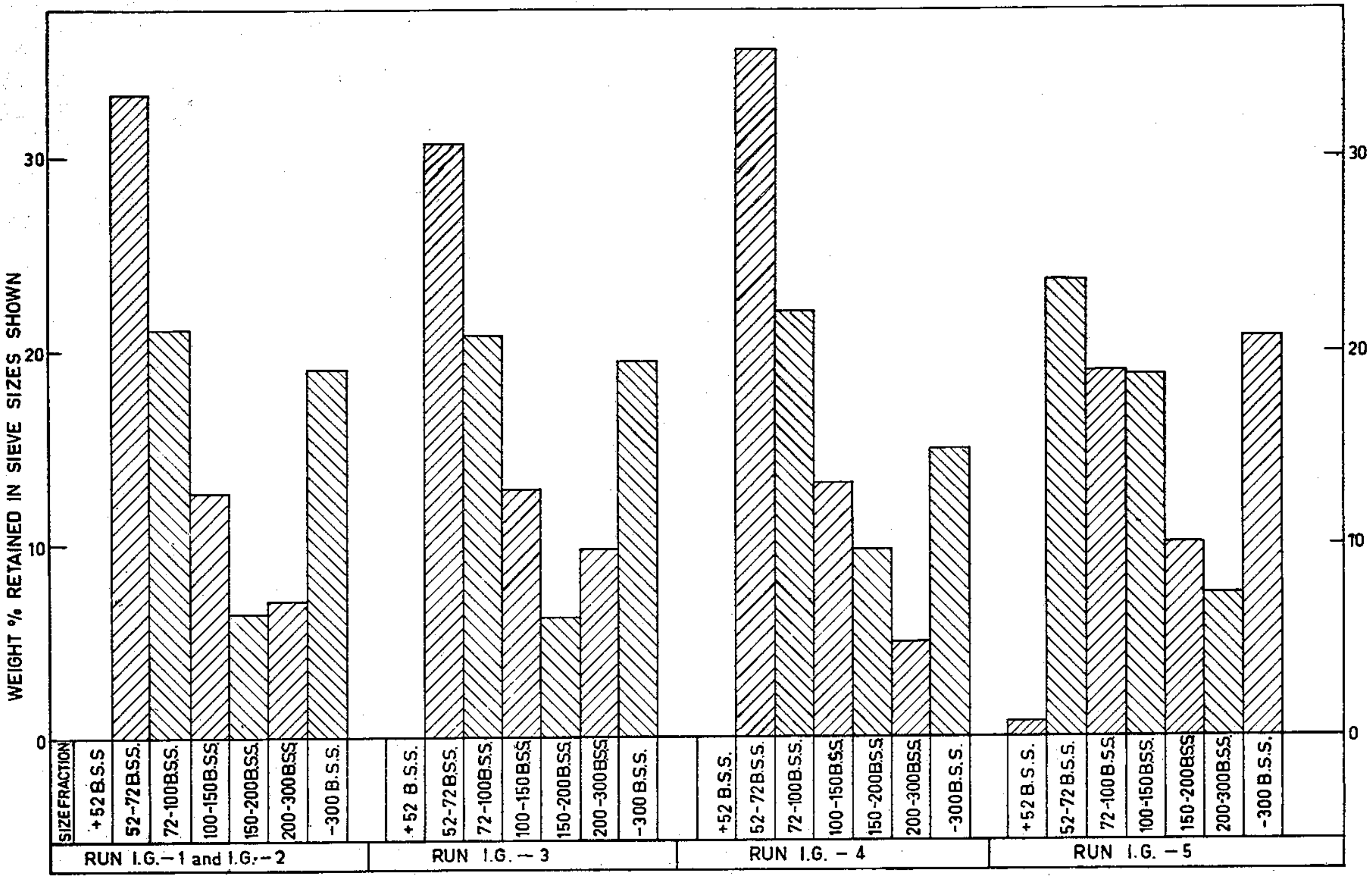

FIGURE 4. SIZE DISTRIBUTIONS FROM INACTIVE GRINDING RUNS

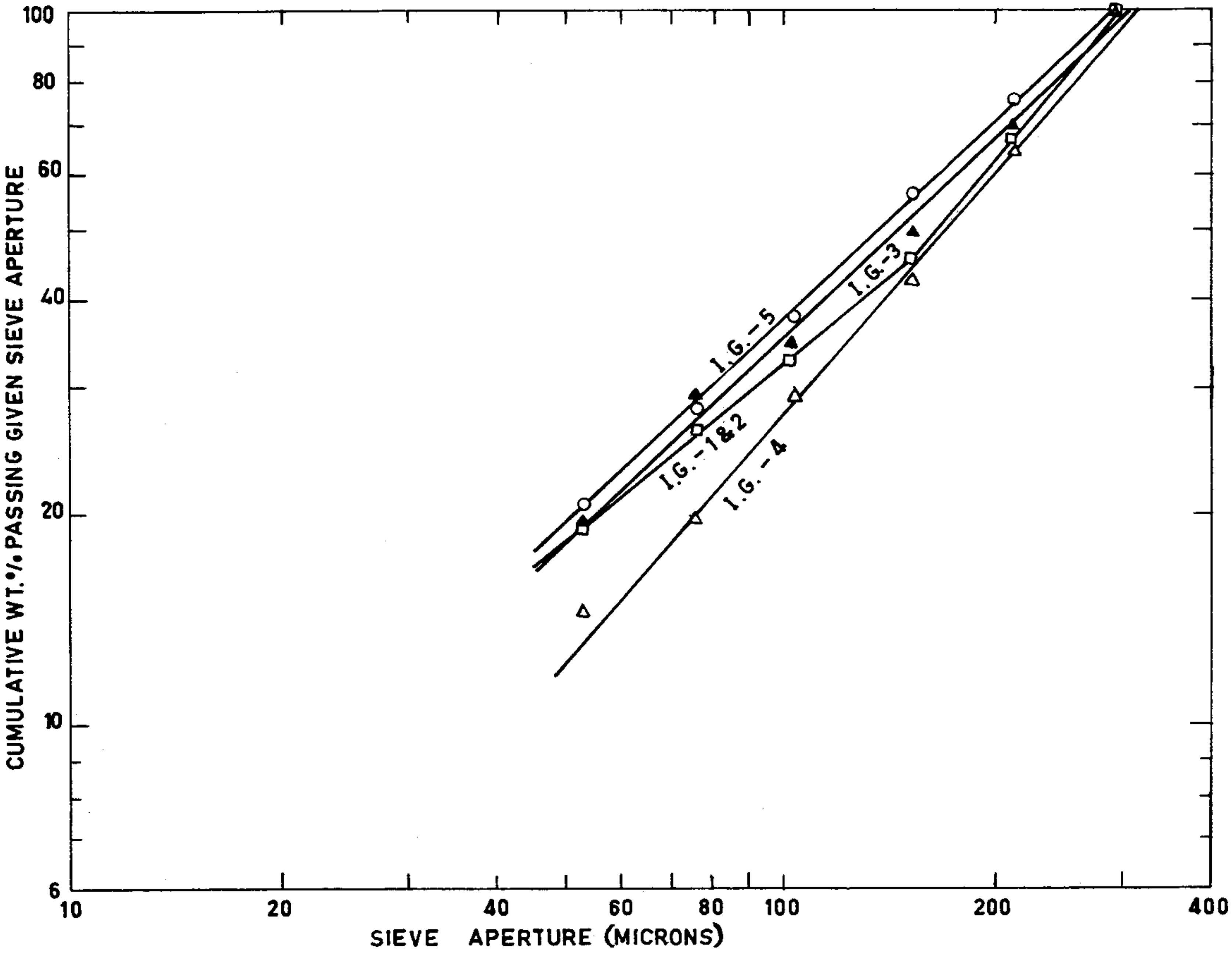

FIGURE 5. GAUDIN-SCHUMANN SIZE DISTRIBUTIONS FROM INACTIVE GRINDING RUNS