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AEC RESEARCH AND DEVELOPMENT REPORT

A SENSITIVE
PNEUMATIC BRIDGE POWDER ANALYZER

AUTHORS:

C. W. Weber
P. R. Kuehn

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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A SENSITIVE PNEUMATIC BRIDGE POWDER ANALYZER

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Oak Ridge, Tennessee

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BRIDGE POWDER ANALYZER

Authors: C. W. Weber and P. R. Kuehn

A B S T R A C T

A rugged, but sensitive, instrument for the rapid determination of true density of a powder has been developed, based on the pneumatic measurement of the true volume of a weighed sample. Transfer of air from a high pressure chamber to the sample chamber gives an equilibrium pressure which is an indirect measure of the sample volume. A differential pressure transmitter measures the equilibrium pressure relative to that in a parallel, reference transfer system. The bridge design increases analytical sensitivity, minimizes temperature effects, and compensates for fluctuations in initial pressures.

Analytical sensitivity is readily varied for different sample types. Composition of binary powder mixtures are directly determined within three minutes. The instrument provides volume measurements with a standard deviation of ± 0.015 cc, yielding true density measurements of handbook quality.

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A SENSITIVE PNEUMATIC BRIDGE POWDER ANALYZER

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A SENSITIVE PNEUMATIC BRIDGE POWDER ANALYZER

Density measurements of powders, and analyses of binary powder mixtures, are commonly needed for process control and industrial research. To fulfill a variety of such needs at the Oak Ridge Gaseous Diffusion Plant, it was attractive to consider a single instrumental approach. For process control, the instrument had to be rugged, but sensitive, and capable of easy maintenance. To permit research application, the instrument needed to be versatile and nondestructive to the sample.

The powder analyzer designed to meet these requirements takes advantage of the variation in true density with powder composition. Most binary powder mixtures exhibit a sufficient density variation with composition to be exploited analytically. The determination of this universal property, true density, permits application of the instrument to materials regardless of other special properties such as electrical or magnetic characteristics and independent of surface area or particle size variations.

In exploring the nondestructive density measurement, the method of gas transfer reported by Byck, Fidiam, and Spell (1) was evaluated briefly to measure the true volume of a weighed sample in a system consisting of two chambers, one containing the sample. While the method proved to be feasible, the device was limited in versatility. The Air Comparison Pycnometer (3,4) was also considered when it became available, but it lacks the necessary sensitivity for many applications.

The principles of gas transfer measurement of true density were extended to the concept of the Pneumatic Bridge Powder Analyzer which meets the requirements of several problems of immediate interest and can be applied to other systems. This report presents the principles of operation and optimization of design, and describes the development of the instrument and its application to several types of powder mixtures.

SUMMARY

A sensitive pneumatic instrument has been developed for the rapid determination of true densities of powders. Based on gas transfer and measurement of true volume of a weighed sample, the system utilizes a differential pressure sensor which gives an equilibrium pressure signal relative to that in a parallel, reference transfer system. The bridge design increases analytical sensitivity, minimizes temperature effects and compensates for fluctuation in initial pressures. Measurements are complete in three minutes.

Sensitivity is readily varied for different powders. Compositions are directly determined in binary mixtures. The instrument provides volume measurements with a standard deviation of ± 0.015 cc; in a mixture of 30% uranium tetrafluoride in aluminum, this is equivalent to a density precision of ± 0.003 g/cc.

Design principles, optimization, experimental details and results are presented. Two instrumental models are described. Application to a variety of powders is discussed.

PRINCIPLES OF OPERATION

Two parallel air transfer systems (figure 1) comprise the pneumatic bridge. Constant volume chambers A and B and transfer valve, V-3, make up the reference leg. The other leg is similar except that one chamber, D, contains a weighed sample. Volumes A and C are identically pressurized with air through valves V-1 and V-2. Opening valves V-3 and V-4 transfers and expands the air in both legs. The difference in equilibrium pressures between the legs after transfer is a measure of the void volume in the sample container D. The procedure is completed by bleeding the system to the atmosphere by opening valves V-5 and V-6.

Single Transfer System

The theoretical basis for the instrument can be developed starting with the equation for gas expansion in a single leg gas transfer system,

$$P_{eq} = \frac{T_2}{T_1} \left(\frac{P_C V_C + P_D V_D}{V_C + V_D} \right) \quad (1)$$

where: P_{eq} = equilibrium pressure after transfer

P_C and P_D = starting absolute pressures in chambers C and D

$T_{1,2}$ = starting and final absolute temperatures

V_C = volume of chamber C

V_D = void volume in chamber D = total volume of chamber D minus true sample volume.

If P_C and P_D are different constant pressures, P_{eq} is a measure of void volume in the sample container. However, application of such a simple system to sensitive analyses requires refined temperature and starting pressure regulation. Fluctuations in the temperature ratio T_2/T_1 are applied to the entire system pressure, only part of which is analytically useful. When applying a sensitive pressure measurement to see the useful signals, thermal drifts give markedly shifting values.

Parallel Transfer System

Through the pneumatic bridge design, using parallel transfer systems, the need for precise pressure regulation is minimized and temperature effects are reduced. These advantages will be shown under OPTIMIZATION OF DESIGN.

Figure 1
BASIC COMPONENTS OF A
PNEUMATIC BRIDGE ANALYZER

Referring to figure 1, the expression for the final pressure differential, ΔP , after the air is expanded simultaneously in the upper (reference) and the lower systems is:

$$\Delta P = \frac{T_2}{T_1} \left(\frac{P_A V_A + P_B V_B}{V_A + V_B} - \frac{P_C V_C + P_D V_D}{V_C + V_D} \right) \quad (2)$$

The terms in parenthesis represent the equilibrium pressures, at constant temperature, for the reference and sample legs of the bridge. All terms except V_D on the right side of the equation are made constants in the analytical application of the Pneumatic Bridge. The differential pressure signal of the instrument, therefore, is a measure of the void volume in the sample tube. This is related to sample volume or density (using a weighed sample) as follows:

$$V_D = V_T - V_S = V_T - \frac{W}{\rho}, \quad (3)$$

where V_D = void volume in the sample container

V_T = total volume in the sample container

V_S = volume of the sample

W = weight of the sample

ρ = density of the sample

For the various compositions of a binary system, sample volume can be written in terms of the density of the constituents and the weight fraction of one component. The above relation between void volume in the sample tube and true sample volume becomes:

$$V_D = V_T - \frac{W\rho_1 + Wf_1(\rho_2 - \rho_1)}{\rho_1 \rho_2} \quad (4)$$

which can be expressed:

$$V_D = V_T - \frac{W\rho_1}{\rho_1 \rho_2} - \frac{W(\rho_2 - \rho_1)}{\rho_1 \rho_2} f_1 \quad (5)$$

where the new terms: ρ_1 and ρ_2 = true densities of the two components

f_1 = weight fraction of component 1.

When all terms on the right except f_1 are made constant by design or procedure, the ΔP signal (Equation 2) is a measure of sample composition.

Linearity of Response

By substitution from Equation 3 into Equation 2,

$$\Delta P = \frac{T_2}{T_1} \left(\frac{P_A V_A + P_B V_B}{V_A + V_B} - \frac{P_C V_C + P_D (V_T - V_S)}{V_C + V_T - V_S} \right)$$

The linearity of ΔP response as sample volume varies is expressed as the differential $d\Delta P/dV_S$. This approaches a constant when V_S is small compared to $V_C + V_T$, the total volume of the sample leg of the system. It can also be shown that for analysis of binary mixtures the ΔP response becomes more linear with composition when the sample volume is relatively small compared with total volume. It should be recognized, however, that for purposes of high analytical sensitivity, it might be preferred to use large samples and accept some nonlinearity.

OPTIMIZATION OF DESIGN

Maximum Sensitivity

To establish the optimum ratio of V_C/V_D for obtaining best sensitivity, one need consider only the sample leg, since all conditions in the reference leg are constant and the corresponding terms will not be retained in differentiation. Using Equation 1 and differentiating with respect to V_D , gives the change in equilibrium pressure with a change in sample volume. Ignoring the temperature ratio,

$$\frac{dP_{eq}}{dV_D} = \frac{V_C (P_D - P_C)}{(V_C + V_D)^2} \quad (7)$$

For a given V_D and fixed $(P_D - P_C)$, the volume of V_C which will make dP_{eq}/dV_D a maximum is found through the derived expression:

$$\frac{d}{dV_C} \left(\frac{dP_{eq}}{dV_D} \right) = \left[\frac{(P_D - P_C)}{(V_D + V_C)^3} \right] [V_D - V_C] \quad (8)$$

The first bracket can never be zero for test conditions; thus the second bracket must equal zero for maximum sensitivity. This is the case when $V_C = V_D$.

Pressure Compensation

Optimum design for minimum effect of starting pressure fluctuations can also be established. For normal operation of the Pneumatic Bridge system, figure 1, starting pressure $P_A = P_C$ and $P_B = P_D$. Under these conditions, differentiating Equation 2 gives:

$$\frac{d(\Delta P)}{dP_A} = \frac{T_2}{T_1} \left(\frac{V_A}{V_A + V_B} - \frac{V_C}{V_C + V_D} \right) \quad (9)$$

and

$$\frac{d(\Delta P)}{dP_B} = \frac{T_2}{T_1} \left(\frac{V_B}{V_A + V_B} - \frac{V_D}{V_C + V_D} \right) \quad (10)$$

Both of these derivatives become zero (minimized) when the ratio V_A/V_B equals the ratio V_C/V_D . This indicates that complete compensation for starting pressure fluctuations can be obtained in design without expensive pressure control devices.

Temperature Compensation

Referring to Equation 2, the temperature ratio, T_2/T_1 , applies to the pressure differential, all of which is analytically useful. This represents a significant improvement over the single leg transfer system, where total pressure signals are affected. In operation of the bridge system, air is transferred simultaneously in the two legs and cooling from decompression occurs in both. A high degree of temperature compensation can be designed into the system. In the final design, temperatures of both legs are equalized by installing corresponding components in adjacent locations. By matching and increasing the total masses of metal in the two legs, the heat capacities are also approximately matched and temperature stability is improved.

In experimental assemblies prior to matching the locations and masses of the main parts, compensation was not complete. As seen in Equation 2, cooling from gas expansion would tend to give a downward drift in ΔP ; however, this drift could be offset by delaying the thermal equilibration of the lower pressure side (volumes $V_C + V_D$) of the bridge. With thin asbestos covers on the large volumes of the lower pressure leg, it did not reach ambient temperature as rapidly as the other leg, after the initial cooling; with this arrangement, the pressure differential of the bridge tended to be constant even at nonequilibrium conditions. The final matched systems do not require these covers.

A valid reading can be taken within 15-20 seconds after gas expansion. With this degree of compensation, the actual level of ambient temperature is not critical; the instrument can be calibrated at one ambient temperature and used at another.

EXPERIMENTAL

The previously discussed principles of optimum design were readily tested experimentally. During instrumental development, two designs were constructed, evaluated, and applied to analytical problems. The first, referred to as the Low Pressure Pneumatic Bridge, was designed for application to relatively large samples (30 - 150 cc true volume) and the internal volumes of the differential pressure transmitter did not need to be small. Its operating pressure can be as high as 80 psig. The second stage of development is called the Intermediate Pressure Bridge and represents an improved design. For application to smaller samples (1 - 30 cc volume), sensitivity was attained by increasing the operating pressure to 200 psig.

Although a High Pressure Bridge (up to 1500 psig) is considered, it has not been designed.

Low Pressure Bridge

A schematic diagram of the Low Pressure Pneumatic Bridge system is shown in figure 2. One-quarter inch OD copper tubing is used throughout the instrument. A 0-100 psig pressure regulator with gauge calibrated in 1 psi subdivisions is satisfactory for controlling starting pressures.

The Low Pressure Bridge was designed around a Taylor differential pressure transmitter (Model 206-RD), which is a bellows-type sensor. Tests indicated that transmitter precision was maintained at operating pressures as high as 80 psig, providing the pressure differential was held within the rated range. A differential pressure (ΔP) range of 50 mm Hg was selected. The volumes of the high and low pressure sides of the three-inch primary bellows in the transmitter assembly were the major contributors to volumes A and C in figure 1. These volumes, measured by gas displacement, were 158 and 137 cc, respectively; the smaller volume (low pressure side of the transmitter) was selected for the sample leg, to permit flexibility of sample size by adding an adjustable volume.

Over-Range Protection. Solenoid valves rated for 150 psig operation are used to regulate gas transfers. Corresponding valves in the two legs of the bridge are wired electrically in parallel and activated simultaneously by a common switch as a first means of preventing transmitter over-range. Further protection is provided by a dual Meletron pressure-sensitive switch, sensing the transmitter output and wired in series with a relay and a pair of solenoid valves connecting the two legs of the bridge. The output range of the transmitters is 3-18 psig; if this range is exceeded by 0.5 psi in either direction, the Meletron switch activates the relay, opening the two safety solenoid valves, allowing pressures to equalize. The relay maintains the solenoids activated until the over-range condition is corrected and a reset switch is operated.

Flow Control. With a powder sample in the sample container, when compressed air is expanded in the bridge, air flows into the empty reference volume faster than into the sample container. The pressure in the reference leg drops below that in the sample leg and tends to over-range the transmitter. To prevent this, a diaphragm-type pressure control valve (Hoke, Inc., Part 1148) was placed in the reference leg. The output from the ΔP transmitter is applied to the bottom of the diaphragm while a larger regulated pressure is applied to the top, causing the valve to close. Flow in the reference leg is, accordingly, controlled by the transmitter output. The capillary by-pass insures final pressure equilibrium in the reference leg.

The large samples dictated by the transmitter volumes, and the limited sensitivity due to restricted charge pressures, prevented acceptable application of this analyzer design when the available sample was small. Also, heat from the solenoid valves affected the precision of these

instruments. This effect was eliminated by air-cooling the solenoid bonnets, but a more suitable valve was used in the subsequent Intermediate Pressure Pneumatic Bridge Analyzer.

Intermediate Pressure Pneumatic Bridge

Selection of Pressure Transmitter. Reducing the sample size and increasing the sensitivity are related problems, since both involve the choice of the differential pressure sensor. It was shown in Equation 8 that best sensitivity is obtained when the void volume in the sample container equals the fixed volume in the sample leg (see figure 1). The fixed volume can be no less than the volume of one side of the sensing element in the transmitter. To keep sample size small, therefore, the differential pressure sensor must have low volume.

Further, in Equation 2, it is obvious that sensitivity increases as the charge pressure increases. For higher pressure operation, it was necessary to abandon bellows-type pressure detectors. Diaphragm-type pressure transmitters were selected since they provide a low pressure side volume of about 25 cc, and they are very rugged. Certain models are designed for operating pressures as high as 1500 psig and a considerable differential pressure over-range is permitted. A selection of full scale ranges from 0-20 to 0-200 in. of water is available in a single transmitter, and range can be changed rapidly and simply. Diaphragm-type transmitters manufactured by Mason-Nielan, Fischer and Porter, Foxborough, and Taylor are suitable for this application.

With the change in transmitter, the total volume of the sample container in the analyzer was reduced from 254 to 36 cc. Due to safety code requirements, the Intermediate Pressure Pneumatic Bridge Analyzer, figure 3, was designed for maximum operating pressures of 200 psig.

Selection of Linear Valves. In the Intermediate Pressure Bridge, valves and connecting tubing were selected for small volume, compared with those in the earlier low pressure model. One-eighth inch OD copper tubing was used and the solenoid valves were replaced with Aerograph 2-position, 6-way, linear-action valves, which have very small volume. Neoprene O-ring seals were acceptable.

Operation of the Analyzer. Figure 3 shows schematically the pneumatic system of the Intermediate Pressure design. The three fundamental steps in obtaining an analytical measurement, as described earlier, are: (1) charging one side of each leg to a high pressure, bringing these charge pressures to equilibrium; (2) transferring (expanding) the gas into the other side of each leg, and reading the equilibrium differential pressure between the reference and sample legs; and (3) bleeding the sample container and its reference counterpart to atmospheric pressure in preparation for the next measurement.

The equivalents of volumes A and C (figure 1) are represented in the volumes to the left of valve L-2 in figure 3; the equivalent of volumes

Figure 3
PNEUMATIC SYSTEM OF THE
INTERMEDIATE PRESSURE PNEUMATIC BRIDGE ANALYZER

B and D are to the right of valve L-2. Table I explains the operating function of the linear valves. Valves L-1 and L-3 are actually mounted in tandem, to move with singular action.

TABLE I
FUNCTION OF LINEAR VALVES IN
INTERMEDIATE PRESSURE PNEUMATIC BRIDGE ANALYZER

<u>Linear Valves</u> (See Figure 3)	<u>Operation</u>
L-1	OUT During Charge (As Shown) IN During Transfer
L-2	OUT to Charge or Bleed (As Shown) IN to Transfer
L-3	OUT to Bleed (As Shown) IN During Transfer

Control of Gas Flows. At charge pressures of 100 psig or more, a pressure control valve, placed close to the transmitter, was necessary in each leg of the Intermediate Pressure Bridge. This location was optimum, allowing only the air entering or leaving the transmitter to be controlled. Although valve L-2 is the manual valve activating the charge or transfer (expansion) steps, the automatic action of the pressure control valves, in effect, moves the limiting constrictions to the left of the adjustable volumes, increasing the reservoir for prompt corrective action to prevent transmitter over-range. Gas flows are also limited by needle valves, as shown in figure 3. This arrangement permits successful use of charge pressures at least as high as 200 psig.

Transmitter Protection. The Meletron switch-solenoid valve protection system described for the Low Pressure Bridge was retained in the Intermediate Pressure Bridge. In addition, manual valve L-3 connects the two legs of the bridge during charging and bleeding, providing further transmitter protection.

Figure 4 shows the electrical wiring for the Intermediate Pressure Bridge. Switches 2 and 3 operate solenoid valves S-2 and S-3 (figure 3) which control the direction of response of the pressure control valves. As indicated, valves S-2 and S-3 permit reversing the application of transmitter output and regulated air pressure at the control valves. The Meletron switch, in series with the relay coil, closes the relay when a transmitter over-range occurs. The circuit made through relay contact 2

LEGEND:

- Electrical Switch
 - Solenoid Valve
 - Relay Contact
 - Relay Coil
 - Light
 - Meletron Switch -
N.C. contact opens at
2.5 psig; N.O. contact
closes at 18.5 psig.
- See Over-Range Protection.

Figure 4
ELECTRICAL WIRING FOR THE
INTERMEDIATE PRESSURE PNEUMATIC BRIDGE ANALYZER

activates block valve S-1 after over-range. The circuit through contact 1 keeps the relay coil activated until the reset switch is opened.

Chamber Design. Figures 5 and 6 show two assemblies of the Intermediate Pressure Pneumatic Bridge. The reference volume and sample container are mounted on the front panel. Throughout the bridge, corresponding components of the two legs are of equal mass and are mounted in close proximity at the same ambient temperature conditions. The chambers slide into connectors and are sealed with O-rings. The chambers are locked in place by the pin-slot design seen in figure 5. A glasswool plug contained in the sample volume connector serves as a self-cleaning filter, preventing particulates from leaving the chamber. A similar plug in the reference connector matches the pressure drop effects.

The adjustable volumes located inside the cabinet (figure 7) are cylinders with pistons (sealed by O-rings) moved by threaded rods. These units permit delicate volume adjustment and provide for versatility in bridge application. It was shown earlier (see OPTIMIZATION OF DESIGN) that best sensitivity results when the two sides of the sample leg have the same effective volume. It is simple to change to a larger sample tube and, by setting the adjustable volume, maintain the desired 1:1 ratio. The addition of solid metal balls to the reference volume is a further device for volume adjustment.

For large powder samples, the sample container must be installed in a horizontal position (figure 6). This provides a flow channel along the top of the container, reducing the depth of powder bed that the air must penetrate and permitting more rapid equilibrium. In some cases it might be advantageous to operate with a powder bed in the reference chamber.

RESULTS

Table II demonstrates the application of the Pneumatic Bridge Powder Analyzers to solid density measurement. The instrument was calibrated with stainless steel balls of known volume. As shown, the agreement with known true densities is excellent, especially for materials with well established values.

Table III shows the results of replicate sampling and measurement on three supplies of impure uranous fluoride. Chemical compositions of the first two samples were calculated from determinations of total fluoride, total uranium, and tetravalent uranium. Assuming uranium dioxide (10.9 g/cc), triuranooctoxide (8.3 g/cc), and uranium tetrafluoride (6.5 g/cc) to be present, theoretical densities were calculated. These compare with the measured values to better than 1% of the density values. Chemical analyses were not available on the third sample. However, the standard deviation for a single measurement is ± 0.03 g/cc. This statistic includes weighing errors and sample inhomogeneity, as well as instrument precision.

Figure 5
INTERMEDIATE PRESSURE PNEUMATIC BRIDGE
POWDER ANALYZER (ADAPTED FOR SMALL SAMPLES)

Figure 6
INTERMEDIATE PRESSURE PNEUMATIC BRIDGE
POWDER ANALYZER (ADAPTED FOR LARGE SAMPLES)

Figure 7
INTERMEDIATE PRESSURE PNEUMATIC BRIDGE
(SIDE VIEW - OPEN)

TABLE II

TRUE DENSITIES DETERMINED BY
PNEUMATIC BRIDGE POWDER ANALYZER

<u>Sample</u>	<u>True Density, g/cc</u>	
	<u>Known (2)</u>	<u>Determined</u>
Copper	8.92	8.91
Zinc	7.14	7.14
Steel	7.86 (Iron)	7.85
Nickel	8.90	8.90
Aluminum	2.70	2.71*
UF ₄	6.4 - 6.6**	6.45*

* Measured on Intermediate Pressure Pneumatic Bridge Powder Analyzer.
All others on Low Pressure Pneumatic Bridge Powder Analyzer.

** Depends on purity.

TABLE III

DENSITIES OF UO_2 - U_3O_8 - UF_4 MIXTURES

<u>Sample</u>	<u>Measured Density*, g/cc</u>	<u>Theoretical Density**, g/cc</u>
1	10.55 10.37 10.42	10.33
2	8.71 8.73 8.73	8.77
3	<div> <div>9.85 9.90 9.82 9.87 9.90</div> <div>} $S_X = \pm 0.034$ g/cc</div> </div>	Mixture Not Analyzed

* Low Pressure Pneumatic Bridge Powder Analyzer.

** Calculated from chemical composition.

Versatility of the Pneumatic Bridge Powder Analyzer for analysis of binary powder mixtures is indicated in table IV. The listed precisions of single measurements of these powdered materials are equivalent to standard deviations of ± 0.015 cc, which is identical to that obtained when measuring nonporous steel balls. Thus the precision of measurement is not limited by the fine particle character of samples, and the expected precision for untested mixtures can be predicted. The calibration curves used to establish the tabulated precisions were prepared from mixtures of known composition. Since the instrument is readily adjusted for concentration ranges of interest, only full-scale ranges of the analyzer are shown.

Data in table V indicate that the accuracy of measurement is approximately as good as the precision. Over the range 22 to 62% aluminum oxide, the measured volumes of known samples agreed with calculated volumes with a standard deviation per single measurement of ± 0.02 cc.

CONCLUSION

The Pneumatic Bridge Powder Analyzer provides a rapid, nondestructive means of density measurement or can be used to determine the composition of binary mixtures. A weighed sample is required, but a determination can be completed in 3-5 minutes. Calibration curves are easily constructed using known volumes or samples of known composition. Response is essentially linear with volume or composition. The instrument is also applicable to powder mixtures other than those tested, and its principles can be applied to solids in general. The precision and accuracy of the instrument permits true density measurements of handbook quality. The instrument is highly versatile by adjustment of volumes, pressures, and sample size, and the system is rugged. In the Intermediate Pressure Analyzer, as designed, samples may vary in bulk volume between 35 and 225 cc, utilizing a choice of sample containers. Of course smaller samples can be measured without the benefit of optimum sensitivity.

The use of pneumatic-electrical transducers, with very small internal volumes, would permit more sensitive measurement of small samples. Very high pressures could be applied in an appropriately designed system to give extremely keen analytical sensitivities.

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TABLE IV

ANALYTICAL RANGES AND PRECISIONS FOR
TYPICAL BINARY MIXTURES*

<u>Mixture</u>	<u>Sample Weight, g</u>	<u>Std. Dev., %(Abs.)</u>	<u>Full Scale Range, %</u>
Al-Al ₂ O ₃	25	±0.29	43
Cu-CuO	75	±0.66	69
UF ₄ -Al	40	±0.12	21

* Characteristic of operation at 100 psig charge pressure, using Intermediate Pressure Pneumatic Bridge Powder Analyzer.

TABLE V

CALCULATED AND MEASURED VOLUMES OF KNOWN
ALUMINUM-ALUMINUM OXIDE MIXTURES

<u>Sample Composition</u>		<u>Calculated Volume, cc, 25 g Sample</u>	<u>Measured* Volume, cc, 25 g Sample</u>	
<u>% Al</u>	<u>% Al₂O₃</u>			
22.14	77.86	7.22	7.20	7.19
29.20	70.80	7.40	7.37	7.39
33.90	66.10	7.52	7.50	7.52
43.05	56.95	7.76	7.77	7.78
50.69	49.31	7.96	7.95	7.97
61.76	38.24	8.24	8.26	8.27

* Intermediate Pressure Pneumatic Bridge Powder Analyzer.

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