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RADIO-FREQUENCY PLASMA AND HEAT TREATMENT OF HUMAN FECAL MATTER

by

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ABSTRACT

Laboratory studies were made to determine the feasibility of adapting the radio-frequency electrodeless discharge method for low temperature ashing of human fecal matter on-board space vehicles. The process assures 100 percent reduction of organic wastes to inorganic forms. The tests were conducted in a 1.5 liter plasma reactor chamber using oxygen, carbon dioxide, hydrogen, water, and a carbon dioxide-hydrogen-water mixture. The effects of treatment gas, discharge power, and gas pressure were studied during low temperature plasma ashing of 'normal' fecal material.

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SUMMARY

This study and evaluation was undertaken to investigate the feasibility of applying low temperature plasma ashing to a major problem of life support on board spacecraft: human solid waste management. Ashing was performed in a 1.5 liter plasma reactor using oxygen, carbon dioxide-hydrogen-water mixture (respiration products). Waste material treated was "normal" human fecal matter from one donor.

The effects of treatment gas, input power, and gas pressure were investigated under laboratory conditions that simulated spacecraft requirements. Detailed analyses were performed on the resulting liquid effluent to determine the suitability of the effluent for recovery as potable water. Analyses were performed on the gaseous products to quantitate carbon dioxide and carbon monoxide.

Treatment of solid waste aboard spacecraft is of primary concern. Most terrestrial waste treatment methods[1], such as high temperature incineration, microwave dehydration, high pressure wet combustion, and a variety of biological processes, would pose some serious problems for spacecraft application. Low temperature plasma ashing, which utilizes radiofrequency (RF) excited gases, provides rapid, efficient, and complete waste management.

In conceiving techniques for solid waste management, consideration was given to the engineering aspects for systems on board which relate to the nature of the treatment system itself as well as the ecological cycles to be sustained.

INTRODUCTION

With the increased durations of future space activities, the management of waste is of primary importance. In the completely closed and sealed environment of a spacecraft or manned orbiting laboratory the problems of waste management include:

1) Space within the spacecraft, which is at a premium, must be occupied by waste products during storage. Waste material must be treated and reduced to a compact and sterile form.

2) Useful products must be efficiently extracted from waste material to be utilized in continuing life support. Water contained in the solid waste must be recovered for reuse, and waste solids must be broken down to efficient building blocks, such as carbon dioxide and water, for the resynthesis of food.

The present study herein is directly applicable to the solution of these problems, and differs significantly from those investigations previously conducted.

The program of investigation utilizing R-F excited gases or R-F heating for the treatment of fecal matter demonstrates certain definite advantages over other approaches to solid waste management. In particular, with respect to optimization of waste handling techniques on board spacecraft, the following advantages are:

1) Compactness of R-F power sources and treatment systems over other sources of power or systems for microwave or high temperature incineration furnaces.

2) Greater efficiency of R-F generated active gases to treat fecal matter versus gases passed at high temperature and pressure for reaction with solid wastes.

3) Efficiency of R-F versus microwave electronic and circuitry techniques to provide active species for reaction with solid wastes.

4) Less power required and superior engineering advantages via R-F techniques to handle larger volumes of material for treatment.

5) Solid residue and gases as effluents have the optimum characteristics for storage, sterility, or disposition into space or absorbants.

6) Ashing at low temperature allows retention of trace elements for subsequent analyses of wastes when returned to earth providing for periodic monitoring of the trace element metabolism of personnel.

EQUIPMENT AND PROCEDURES

Plasma Reactor System

The plasma reactor with gas delivery system and effluent separation are shown in Figure 1. This reactor design appears most effective for the interaction of the solid material with the active plasma. Fecal specimen boat in holder (Figure 3) is placed in the plasma reactor through the entry port (Figure 2). The reactor tube is provided with an excitor coil from which the R-F energy is delivered. The power is ultimately derived from a Tracerlab RFG-3000 generator and the energy is efficiently coupled into the gas load by a Tracerlab PAI-3000 plasma activator at 13.56 megacycles/sec. When the power is increased to 500 or 1000 watts, a discharge is initiated and a flow discharge concentration of active, reactive species is generated. After the excited gas species has been produced, and ashing has taken place, the gas is swept out of the system and deactivates rapidly due to wall and volume collisional processes. The deactivated gas and effluents are separated next in the effluent collection section.

Paired dry ice-acetone traps were employed to insure recovery of water extracted from fecal matter. Effluent gaseous products were collected in a 500 cc stainless steel bomb containing a fiberglass barrier for retention of gas. The gas bomb was immersed in a liquid nitrogen bath. Uncollected gases are exhausted by a mechanical vacuum pump.

Dehydration Procedure

Dehydration of feces is required before effective R-F discharge ashing of feces. The high (71 per cent) water content of the feces treated causes a gas pressure of 4-5 mm. of Hg. in the plasma reactor, thus extinguishing the R-F discharge. The dehydration procedure is summarized below.

1) Assemble clean apparatus for low vacuum dehydration of fecal material, refer to Figure 1.

2) Record tare weights of water traps No. 1 and No. 2.

3) Record tare weight of clean 8 x 2 x 1 cm. pyrex sample boat.

4) Record weight of about 5 grams of feces in boat and determine surface area of sample.

5) Dehydrate sample for 2 hours at 105° C. under 20 cm. of Hg. vacuum.

6) Record weight loss of fecal sample and retain sample for plasma ashing.

7) Record weight of water recovered in traps No. 1 and No. 2. Combine contents of both traps in sterile sample bottles and retain water samples for subsequent tests: sterility, pH, color, odor, and appearance.

Plasma Ashing Procedure

The R-F discharge ashing procedure is summarized below.

Fecal ashing was performed according to the procedure outlined in Contract No. NAS 2-4702, except for revision of part A. 3. of Article I-Statement of work. It was mutually agreed between Ames Research Center and Tracerlab that 500 and 1000 watt power levels shall be investigated.

1) Place dehydrated fecal sample in reaction chamber and evacuate to a background pressure of 25 microns of Hg. for vacuum leak test.

2) Adjust reactor gas pressure with McLeod guage No. 1 to 1.0 mm. of Hg. with selected gas from gas manifold, refer to Fig. 1. Monitor the time, power, gas flow rate, and gas pressure during the ashing period.

3) Ash sample of selected power level and weigh sample at one hour intervals until weight loss becomes constant. Plot sample weight-ashing time curves, refer to Figures 4 and 5.

4) Collect gaseous products in a 500 cc. stainless steel gas bomb immersed in a liquid nitrogen bath.

5) Record weight of water recovered in traps No. 1 and No. 2. Combine water recovered with water from dehydration in a sterile sample bottle for sterility test.

6) Record weight, surface area, and appearance of residual fecal ash. ash to sterile sample bottle for subsequent sterility test.

SPECIMEN SAMPLES

A sample quantity of 5 grams was selected to produce sufficient amounts of effluents for analyses. 'Normal' fecal specimens from one donor were composed of about 29 per cent of organic materials and 71 per cent water. Tracerlab is aware that feces obtained through the prescribed 'Space diet' on both the MORL and long mission flights will have a different composition. This change will be most noticeable in the water/solid ratios. Specimens were obtained in a polyethylene bag, placed in a dry ice freeze storage, and later transferred for sample preparation.

ANALYSES OF EFFLUENTS

Bacteriological sterility tests (3) were performed on the water recovered and residual fecal ash. Each specimen was planted in liquid thioglycollate media and incubated for 24 hours. It was then transferred to blood agar plates for observation of colony growth. The test was reported as bacteria growth shown or no growth. Gaseous products collected were analyzed for carbon dioxide and carbon monoxide by gas chromatography. A twin column chromomatograph with a thermal conductivity detector was used. Column packing consisted of Porapaq Q. Helium was used as the carrier gas. Methane at standard conditions was used as an interval standard for quantitation of gases analyzed.

Results and Discussion

Complete results of feces ashing experiments are summarized in Tables I to III. Gas chromatography analysis of the gas samples examined shows the presence of CO_2, CO, gas A and B. Gases A and B are tentatively identified as NO_2 and H_2S. Efficient collection of effluents was not obtained because of the low operating pressure as shown in Table IV. Ashing rate curves for the treatment gases investigated are shown in Figures 4 and 5.

Fecal Ashing Experiments with Oxygen

The following was accomplished: the final residual fecal ash and water recovered were determined to be sterile. The weight of unsterile feces residue was reduced by a factor of 3.0 to sterile ash, with other materials being evolved as gaseous products, such as CO_2, CO, NO_2, H_2S, and water vapor. The consumption of oxygen was efficient but less efficient than hydrogen; 2.4 grams consumed per gram of feces volatilized at 1000 watts power for three hours.

Fecal Ashing Experiments with Carbon Dioxide

The final residual ash and effluent water were determined to be sterile. The weight of unsterile feces residue was reduced by a factor of 3.4 to sterile ash.

The consumption of carbon dioxide was less efficient than hydrogen; 4.3 grams consumed per gram of feces volatilized at 1000 watts power.

The ashing rate of CO_2 for fecal materials is faster than that of O_2 or H_2O, refer to Figures 4 and 5.

Fecal Ashing Experiments with Hydrogen

The final residual ash and effluent water were found to be sterile. The weight of unsterile feces residue was reduced by a factor of 3.0 to sterile ash. The consumption of hydrogen was more efficient than any other gas investigated; 0.02 grams consumed per gram of feces volatilized at the 1000 watt power level.

Fecal Ashing Experiments with Water

The final residual ash and effluent were determined to be sterile. The weight of unsterile feces residue was reduced by a factor of 3.1 to sterile ash.

The consumption of activated water was less efficient than hydrogen; 4.3 grams consumed per gram of feces volatilized at the 1000 watt power level.

Fecal Ashing Experiments with 1:1:1 Carbon Dioxide-Hydrogen-Water

The treatment gas mixture represents use of respiration products. The final residual ash and effluent were determined to be sterile. The weight of unsterile feces residue was reduced by a factor of 3.5 to sterile ash.

The consumption of the CO_2-H_2-H_2O mixture was less efficient than hydrogen; 3.8 grams consumed per gram of feces volatilized at the 1000 watt power level.

The ashing rate of the 1:1:1 gas mixture containing CO_2 is faster than that of O_2 or H_2O, refer to Figures 4 and 5.

APPLICATION AND ENGINEERING ASPECTS OF PLASMA ASHING

Several engineering aspects were studied in relation to the application of low temperature plasma ashing to spacecraft waste systems. In particular, with respect to optimization of waste handling techniques on board spacecraft, the following considerations are given:

1) This study indicates efficient and complete treatment of human fecal matter with R-F excited hydrogen. Oxygen aboard the space station will be a precious commodity, and it is thus deemed desirable to use hydrogen. Solid fecal ash and gases as effluents have the optimum characteristics for storage, sterility and disposition into space or absorbants.

2) It would appear feasible that 'space' vacuum could be used to operate the R-F plasma vacuum system. Less power would be required to handle larger volumes of material for treatment.

3) Waste solids can be broken down to efficient building blocks, such as carbon dioxide and water, for the resynthesis of food. Water extracted from the waste material can be recovered for reuse.

4) R-F power sources and treatment systems have the important advantages of being made compact, completely automatic or with manual control, with very little maintenance requirements.

CONCLUSIONS

Several conclusions can be drawn from this study in regard to the feasibility of very small scale plasma ashing systems and their possible application to spacecraft waste treatment systems.

1) Low temperature plasma ashing of human fecal matter was feasible and efficient in very small systems. Virtually 100% reduction of organic solid wastes to inorganic ash was achieved by the process. This study indicates that a properly designed plasma treatment system should be applicable to spacecraft waste treatment.

2) The use of pure hydrogen proved to be very satisfactory and resulted in a three-fold reduction in unsterile feces to sterile residual ash. About 0.1 gram or less hydrogen was required for each gram of dry waste solids.

3) The final residual waste was entirely composed of a light grey or dark porous, sterile inorganic ash. The water recovered was clear, colorless, and sterile. These results indicate that water recovered by this treatment method could be reused with minimum processing.

4) The gases and vapors produced by plasma ashing of solid fecal wastes are primarily CO_2 and water vapor with low concentrations of CO, NO_2, and H_2S. However, the collection of the total effluents was not efficient enough to show real differences in the fecal samples volatilized with the various treatment gases.

5) Further effort should be devoted to the application of low temperature plasma ashing to spacecraft waste treatment.

REFERENCES

1) Pipes, W. O. Waste-Recovery Processes for a Closed Ecological System, Nat. Acad. of Sciences - Nat. Research Council Publication 898, Washington, D. C., 1961.

2) Quon, J. E. and Pipes, W. O. "Thermal Decomposition of Human Wastes." Proceedings ASCE, 89, No. SA1, January, 1963.

3) Bergey's Manual of Determinative Bacteriology, 7th ed., Williams and Wilkins, 1957.

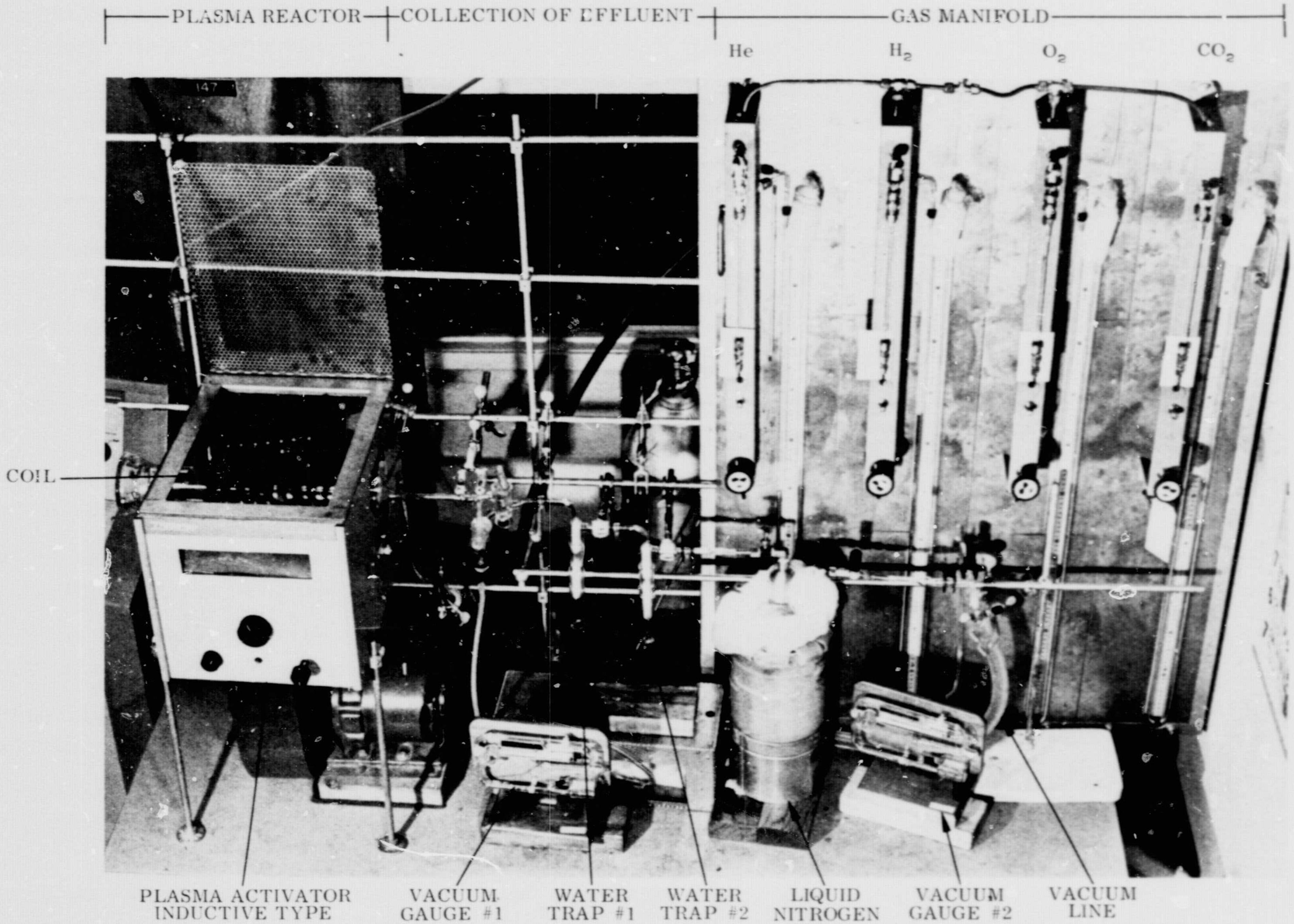

FIGURE 1 PLASMA ASHING SYSTEM - EFFLUENT COLLECTION FOR HUMAN FECAL MATTER STUDIES

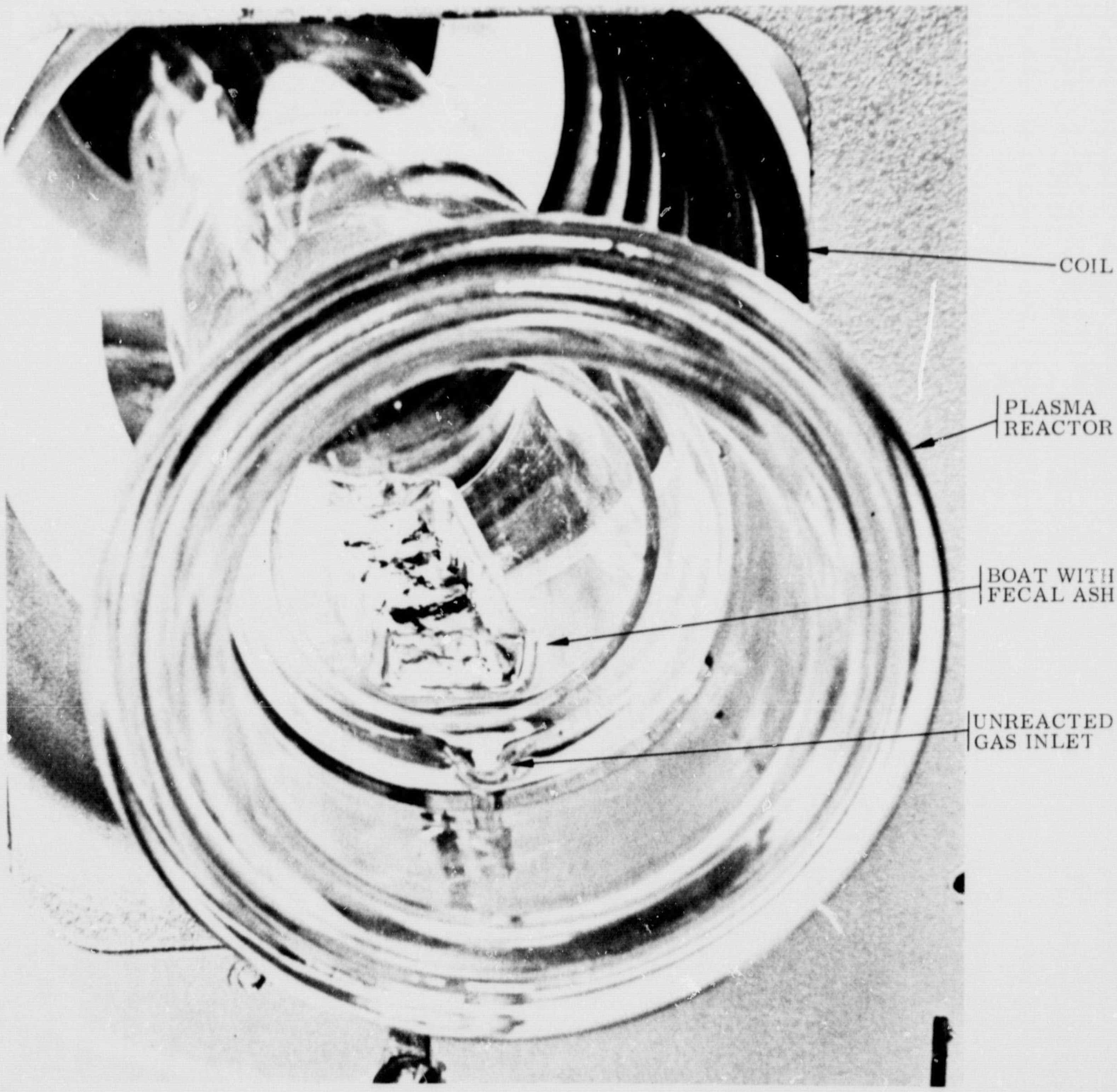

FIGURE 2 FECAL SPECIMEN ENTRY PORT OF PLASMA REACTOR

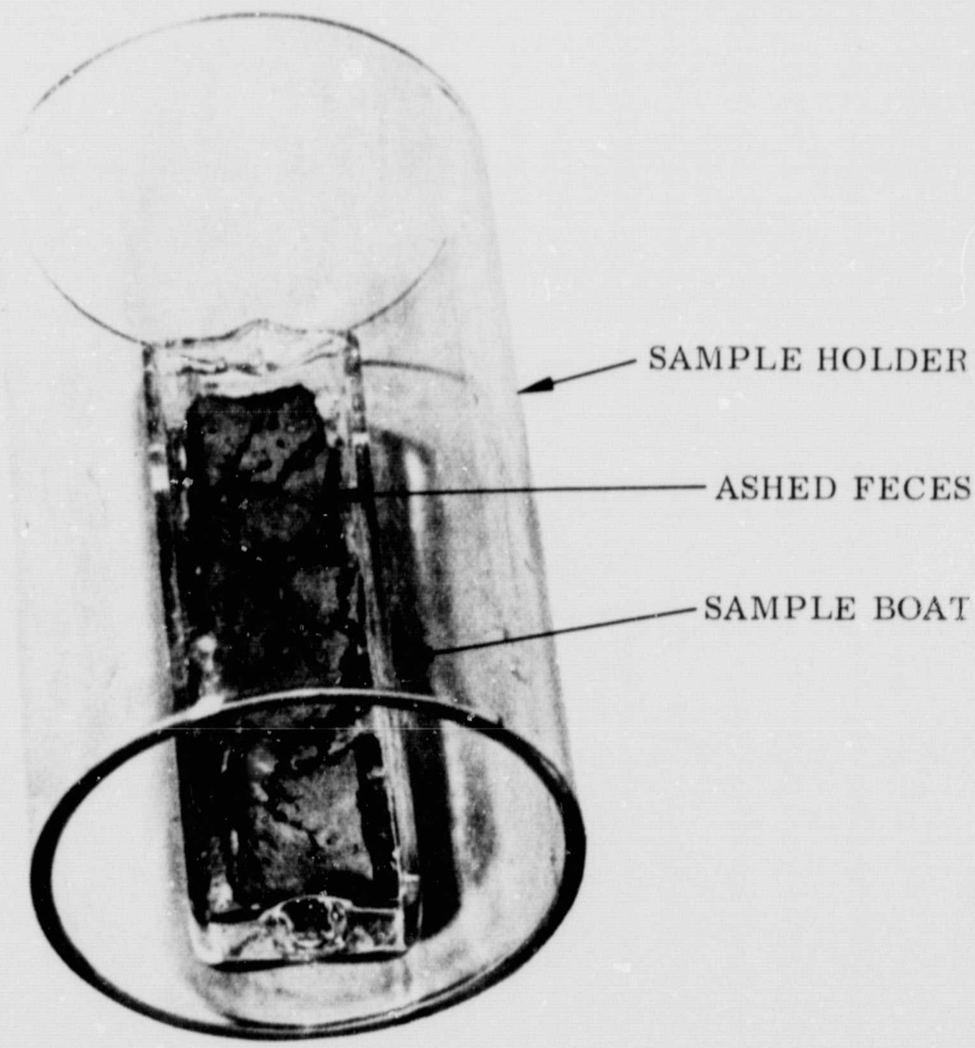

FIGURE 3 FECAL SPECIMEN BOAT IN HOLDER

FIGURE 4 HUMAN FECAL MATTER ASHED IN O_2, CO_2, H_2O, CO_2-H_2-H_2O

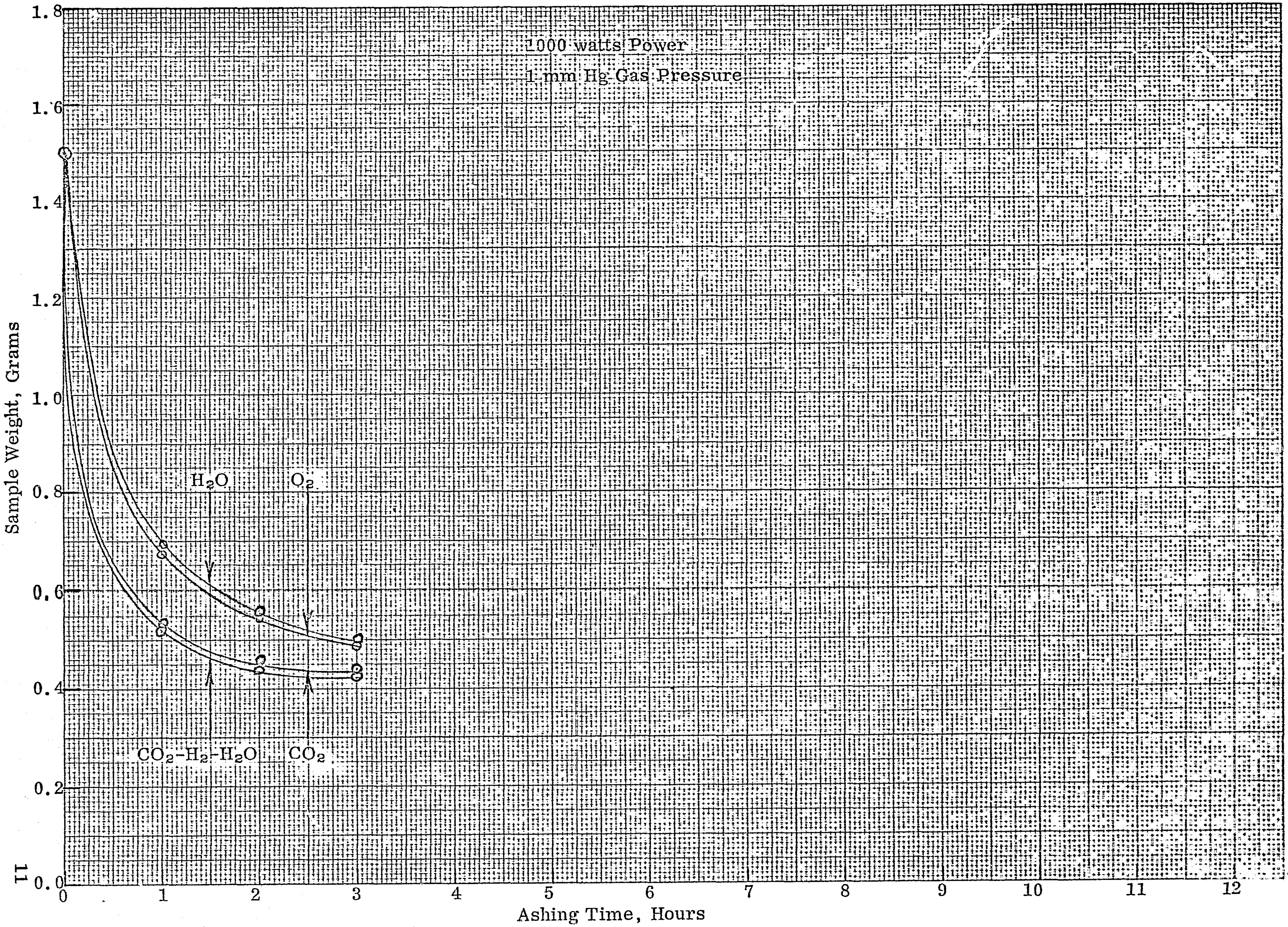

FIGURE 5 HUMAN FECAL MATTER ASHED IN O_2, CO_2, H_2O, CO_2-H_2-H_2O

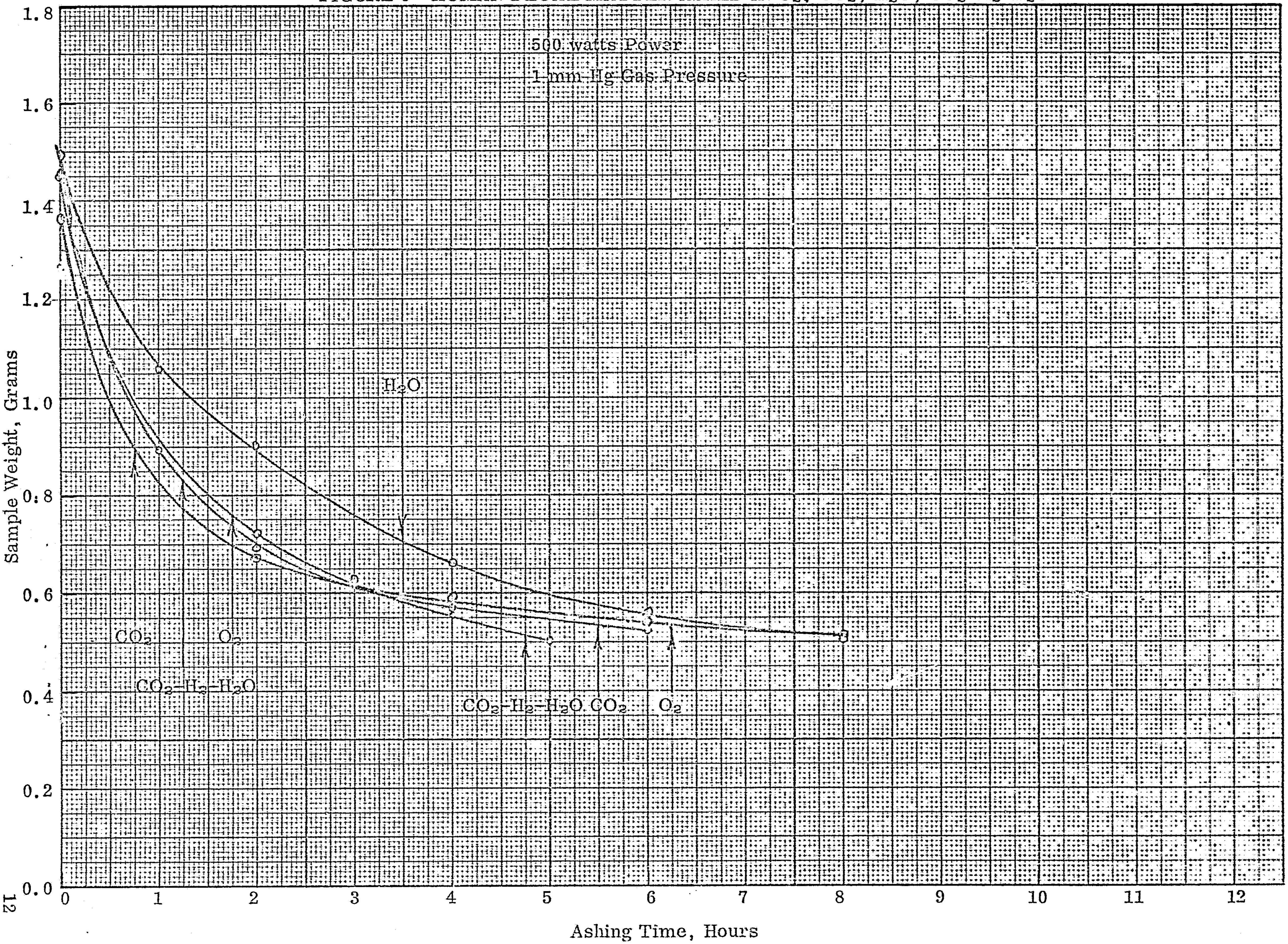

TABLE I

SUMMARY OF PLASMA ASHING EXPERIMENTS OF HUMAN FECAL MATTER

Sample No.	1-HFM-O2	2-HFM-O2	1-HFM-CO2	2-HFM-CO2
Initial (moist) wt of feces, g.	5.079	5.042	5.018	5.011
Surface area, cm^2	39.5	42.1	44.7	48.3
Appearance	'normal' feces	'normal' feces	'normal' feces	'normal' feces
Thermal dehydration of feces				
Water removed (by diff.), g.	3.623	3.552	3.651	3.514
Residue remaining, g.	1.456	1.490	1.367	3.514
Water removed, %	71.3	70.4	72.8	70.1
Sterility of Residue	not sterile	not sterile	not sterile	not sterile
RF Plasma Ashing of Fecal Residue				
Gas type	O_2	O_2	CO_2	CO_2
Discharge power, watts (continuous)	500	1000	500	1000
Gas pressure, torr	1.0	1.0	1.0	1.0
Total ashing time, hours	5.0	3.0	6.0	3.0
Gas used, g.	1.99 O_2	1.19 O_2	2.75 CO_2	1.65 CO_2
Residual ash, g.	0.504	0.488	0.542	0.440
Gas used, g/residual ash, g	4.0	2.4	5.6	4.3
Surface area, cm^2	15-20	15-20	15-20	15-20
Sterility of residual ash	sterile	sterile	sterile	sterile
Appearance of ash	lt gry, porous	lt gry, porous	lt gry, porous	lt gry, porous
Effluent water collected, ml	3.6	3.5	3.7	3.5
Sterility of effluent water	sterile	sterile	sterile	sterile
pH	9.0	8.9	8.9	8.7
Odor	nitrogen	nitrogen	nitrogen	nitrogen
Appearance	translucent	translucent	translucent	translucent
Color	none	none	none	none
Effluent Gas Analysis (1)				
mg CO_2	13.7	82.0	275.0	535.0
mg CO	11.6	6.2	15.6	12.9
mg A (2)	trace	5.3	trace	67.7
mg B (2)	trace	11.4	trace	22.6
mg total gas	25.3	104.9	290.6	638.2
Effluent water, g	0.422	0.413	0.452	0.371
Residue volatilized, g.	0.952	1.002	0.825	1.057

(1) by gas chromatography

(2) A and B gases tentatively identified as NO_2 and H_2S, respectively.

TABLE II

SUMMARY OF PLASMA ASHING EXPERIMENTS OF HUMAN FECAL MATTER

Sample No.	1-HFM-H2	2-HFM-H2	3-HFM-H2	1-HFM-H2O
Initial (moist) wt of feces, g	12.891	14.284	11.744	5.063
Surface area, cm^2	53.6	49.8	51.3	44.7
Appearance	'normal' feces	'normal' feces	'normal' feces	'normal' feces
Thermal dehydration of feces				
Water removed (by diff.), g.	9.162	10.259	5.616	3.569
Residue remaining, g.	3.729	4.025	6.128	1.494
Water removed, %	71.1	71.8	47.8	70.5
Sterility of Residue	not sterile	not sterile	not sterile	not sterile
RF Plasma Ashing of Fecal Residue				
Gas type	H_2	H_2	H_2	H_2O
Discharge power, watts (continuous)	500	750	1000	500
Gas pressure, torr	1.0	1.0	1.0	1.0
Total ashing time, hours	19.5	11.0	5.0	8.0
Gas used, g.	0.49 H_2	0.19 H_2	0.13 H_2	3.70 H_2O
Residual ash, g.	2.473	1.975	1.262	0.503
Gas used, g/residual ash, g	0.13	0.05	0.02	7.4
Surface area, cm^2	27	20	17	15-20
Sterility of residual ash	sterile	sterile	sterile	sterile
Appearance of ash	dark, porous	dark, porous	dark, porous	lt gry, porous
Effluent water collected, ml	7.7	9.0	8.0	3.6
Sterility of effluent water	sterile	sterile	sterile	sterile
pH	8.4	7.7	8.3	8.7
Odor	nitrogen	nitrogen	nitrogen	nitrogen
Appearance	translucent	translucent	translucent	translucent
Color	none	none	none	none
Effluent Gas Analysis (1)				
mg CO_2	13.6	62.4	74.8	204.0
mg CO	30.2	0.7	34.9	4.3
mg A (2)	51.9	68.4	105.0	6.0
mg B (2)	44.6	36.4	31.1	7.0
mg total gas	140.3	167.9	245.8	221.3
Effluent water, g	-	-	-	0.411
Residue volatilized, g	1.256	2.050	4.866	0.991

(1) by gas chromatography

(2) A and B gases tentatively identified as NO_2 and H_2S, respectively.

TABLE III

SUMMARY OF PLASMA ASHING EXPERIMENTS OF HUMAN FECAL MATTER

Sample No.	2-HFM-H2O	1-HFM-CO2-H2-H2O	2-HFM-CO2-H2-H2O
Initial (moist) wt of feces, g	5.062	5.044	5.034
Surface area, cm^2	47.2	41.1	40.6
Appearance	'normal' feces	'normal' feces	'normal' feces
Thermal dehydration of feces			
Water removed (by diff.), g	3.560	3.582	3.518
Residue remaining, g	1.502	1.462	1.516
Water removed, %	70.3	71.0	69.9
Sterility of residue	not sterile	not sterile	not sterile
RF Plasma Ashing of Fecal Residue			
Gas type	H_2O	1:1:1 CO_2:H_2:H_2O	1:1:1 CO_2:H_2:H_2O
Discharge power, watts (continuous)	1000	500	1000
Gas pressure, torr	1.0	1.0	1.0
Total ashing time, hours	3.0	6.0	3.0
Gas used, g	0.62 H_2O	3.30 CO_2-H_2-H_2O	1.65 CO_2-H_2-H_2O
Residual ash, g	0.493	0.531	0.437
Gas used, g/residual ash, g	4.3	6.2	3.8
Surface area, cm^2	15-20	15-20	15-20
Sterility of residual ash	sterile	sterile	sterile
Appearance of ash	lt gry, porous	lt gry, porous	lt gry, porous
Effluent water collected, ml	3.5	3.6	3.5
Sterility of effluent water	not sterile	sterile	sterile
pH	8.8	8.6	8.9
Odor	nitrogen	nitrogen	nitrogen
Appearance	translucent	translucent	translucent
Color	none	none	none
Effluent Gas Analysis (1)			
mg CO_2	57.8	590.0	197.0
mg CO	1.0	0.5	0.4
mg A (2)	20.3	3.7	21.3
mg B (2)	7.0	6.5	9.1
mg total gas	86.9	600.7	227.8
Effluent water, g	0.492	0.784	0.382
Residue volatilized, g	1.009	0.931	1.079

(1) by gas chromatography

(2) A and B gases tentatively identified as NO_2 and H_2S, respectively.

TABLE IV

FECES - EFFLUENT MATERIAL BALANCE

Sample No.	Feces Volatilized, g.	Total Effluents[a] Collected, g.	Effluents[a] Not Collected (by diff.), g.
1-HFM-O2	0.952	0.447	-0.505
2-HFM-O2	1.002	0.518	-0.484
1-HFM-CO2	0.825	0.743	-0.082
2-HFM-CO2	1.057	1.009	-0.048
1-HFM-H2	1.256	0.140[b]	-1.116
2-HFM-H2	2.050	0.168[b]	-1.882
3-HFM-H2	4.866	0.246[b]	-4.620
1-HFM-H2O	0.991	0.632	-0.359
2-HFM-H2O	1.009	0.579	-0.430
1-HFM-CO2-H2-H2O	0.931	1.385	+0.454
2-HFM-CO2-H2-H2O	1.079	0.610	-0.469

a Includes gaseous products plus effluent water.

b Effluent water not included.