DP-MS-79-51

THE USE OF HELIUM-3 AS A GAS TRACER FOR MESOSCALE METEOROLOGICAL STUDIES

by*

J. E. Halverson, M. M. Pendergast, A. L. Boni

E. I. du Pont de Nemours and Company
Savannah River Laboratory
Aiken, South Carolina 29801

To be presented at the Atmospheric Tracer Workshop
to be held in Los Alamos, NM on May 23-24, 1979

This paper was prepared in connection with work under Contract No. AT(07-2)-1 with the U.S. Department of Energy.

THE USE OF HELIUM-3 AS A GAS TRACER FOR MESOSCALE METEOROLOGICAL STUDIES

by*

J. E. Halverson, M. M. Pendergast, A. L. Boni

E. I. du Pont de Nemours and Company
Savannah River Laboratory
Aiken, South Carolina 29801

INTRODUCTION AND SUMMARY

In order to conduct studies of atmospheric diffusion over distances of 100 to 1000 km, it is necessary to use tracers which are nonreactive, easy to sample, easy to measure above global background, have few other sources, and have no biological significance to man. Highly pure helium-3, the decay product of tritium is one such tracer. As a noble gas, helium-3 is not reactive or hazardous upon release to the atmosphere, which yields a very stable background and simplifies interpretation of results. New gas mass spectrometric techniques permit measurements of as little as 5×10^4 atoms of helium in 1 cubic centimeter of air. This sample size is small enough that large numbers of samples can be easily collected. The amount released in mesoscale meteorological studies would be very small compared to the global inventory of helium-3.

---

*The information contained in this article was developed during the course or work under Contract No. AT(07-2)-1 with the U.S. Department of Energy.

Helium-3 as an Atmospheric Tracer

For any material to be useful as an atmospheric tracer it must meet several criteria: low background levels of the material in the atmosphere, absence of effects that may confuse intepretation of the results (other sources, reactions of the tracer with the atmosphere or other environmental entities, etc.), no deleterious effect on the environment, ease of release and sampling, accurate and facile analysis procedure, and availability and purity of the tracer. Helium-3 meets all of these criteria within acceptable limits.

The atmospheric helium-3/helium-4 abundance ratio [1.384×10^{-6} ($\pm$ 0.4%)][1] and the atmospheric concentration of helium (5.24 ppm)[2] can be used to calculate that the atmospheric concentration of helium-3 is 7.25 ppt. Although this is a fairly high background level, it is very stable and any variations greater than or equal to 1 ppt would result in significant data. There are few known sources of helium-3 that could cause this background level to vary greatly.

One of the main attractions of using helium-3 as a tracer is the fact that it is an inert gas, which results in no reactions between it and any environmental agents causing depletion of the tracer. Helium-3 is not chemically reactive or radioactive and has no damaging effect on the environment. The quantity of helium-3 released in any proposed meteorological study would not add significantly to the world inventory of helium-3.

The sensitivity of the proposed sample analysis procedure, allows simple sampling and release methods. The amount of helium-3 in one standard milliliter of air is more than adequate to measure accurately (<1% error) the atmospheric concentrations of helium-3. Thus, whole air samples can be collected by opening small evacuated sample bottles, making manual, automatic, sequential, mobile and time-integrated sampling possible.

Analysis Procedure

A specially designed static gas mass spectrometer (presently under construction for Savannah River Laboratory), shown schematically in Figure 1, will be used to measure helium-3/helium-4 abundance ratios in the atmospheric samples. Such an instrument is presently being used at McMaster University and Woods Hole Oceanographic Institution for a variety of investigations involving measurements of helium-3. These instruments can measure quantities of helium-3 as small as 2×10^{-15} std cc within 10%. Since the background of helium-3 concentration is 7.25 ppt, analysis of air samples as small as 1 cc will not be difficult. The limiting factor on the quantity of helium-3 tracer required and the range to which helium-3 is a useful tracer is the degree to which background is a constant and the accuracy to which any excess in the helium-3/helium-4 ratio can be measured. For the calculation which follows, it is assumed that any change of 1 ppt in the air concentration of helium-3 would be measurable.

Useful Ranges and Tracer Release Quantities

Detection Limits for an Instantaneous Release (Puff)

The work of Heffter (3) was used to estimate nominal values for growth rate of an instantaneous release of helium-3. The standard deviation of concentration distribution in the cross-wind direction (σ_y) was calculated using experimental data distances between 10 and 10,000 km (Figure 2). The dashed line and the solid line were added to represent growth rates of a puff released during stable and unstable conditions.

The relative concentration is related to the value of σ_y according to

$$\chi/Q = \frac{1}{\sqrt{2}(\pi^{3/2})\sigma_y\sigma_x\sigma_z}$$

where χ/Q is the ground level puff centerline relative concentration resulting from a puff and σ_y, σ_x, and σ_z are the standard deviations of the concentration distributions in the crosswind, along wind and vertical directions at a distance, χ/Q are valid for a surface release. For purpose of this estimate the following assumptions are made:

$\sigma_x = \sigma_y$

σ_z = 1000 m for unstable conditions

σ_z = 500 m for stable conditions

Using Equation 1, and Figure 2, and the above assumptions, relative concentrations for stable and unstable conditions were determined for distances 10-10,000 km. (Table 1). The conservative assumption $\sigma_x = \sigma_y$ is often made, but researchers have shown that at large distances $\sigma_x > 2\,\sigma_y$ so relative concentrations may be too high in this assessment.

It is assumed that an air concentration of 1 ppt of helium-3 = 1.3×10^{-10} g/m^3 is sufficiently above the normal variation of background. The amount of helium-3 required to achieve this concentration for different distances and stability conditions is shown in Table 2. From these results, it is apparent that helium-3 can be a useful puff tracer under certain meteorological conditions at distances up to 1000 km.

Detection Limits for a Continuous Release (Plume)

Relative concentrations given in Table 3 were extracted from a theoretical curve given in Reference 4 for two cases. The stable case was assumed to be represented by Pasquill stability class F, wind speed of 3 m/sec and a mixing depth of 500 m. The unstable case is assumed to be represented by Pasquill stability class B, wind speed of 5 m/sec, and a mixing depth of 1000 m.

The results for χ/Q listed in Table 3 were used to calculate release rates which would result in atmospheric concentrations of 1 ppt along the plume centerline.

Table 4 lists integrated quantities of helium-3 needed to be released to result in concentrations of 1 ppt at distances of 10 km and 100 km.

The values listed in quotes in Table 3 and 4 are extrapolations of a theoretical curve to indicate approximate outer bounds of usefulness. These results indicate that helium-3 can be a useful tracer for plume releases at distances greater than 100 km.

REFERENCES

1. W. B. Clarke, W. J. Jenkins, and Z. Top. *Inter. Jour. Appl. Radia. Isotopes,* 27, 515-522, (1976)

2. M. Nicolet. *Physics of the Upper Atmosphere.* J. A. Ratcliffe, editor, p. 17, Academic Press, New York (1960).

3. J. L. Heffter. *Meteorology and Atomic Energy.* D. H. Slade, editor, U. S. Atomic Energy Commission, Office of Information Services (1968).

4. D. B. Turner. *Workbook of Atmospheric Dispersion Estimates.* U. S. Public Health Service (1969).

TABLE 1

RELATIVE CONCENTRATIONS (χ/Q) RESULTING FROM AN INSTANTANEOUS POINT SOURCE. VALUES OF χ/Q REPRESENT THE MAXIMUM GROUND LEVEL VALUE AT THE CENTER OF THE PUFF

Downwind Distance, km	*Stable χ/Q, m^{-3}*	*Unstable χ/Q, m^{-3}*
10	2.8×10^{-9}	1.3×10^{-10}
100	2.8×10^{-11}	1.3×10^{-12}
1000	2.8×10^{-13}	1.3×10^{-14}
10,000	2.8×10^{-15}	1.3×10^{-16}

TABLE 2

AMOUNT OF ^3He NEEDED TO BE RELEASED IN ORDER TO RESULT IN AIR CONCENTRATION OF 1 PPT AT SEVERAL DISTANCES DOWNWIND

Downwind Distance, km	*Amount of He Released, g* *Stable*		*Unstable*	
10	0.05 g	(.37 L)	1.0	(7.5 L)
100	4.6 g	(35 L)	100	(75 L)
1000	464.0	(3500 L)	1,000	(7,500 L)
10,000	46,400	(350,000 L)	100,000 g	(750,000)

TABLE 3

RELATIVE CONCENTRATIONS (χ/Q) RESULTING FROM A CONTINUOUS GROUND LEVEL RELEASE. VALUES OF χ/Q REPRESENT THE MAXIMUM GROUND LEVEL VALUE AT THE CENTER OF THE PLUME

Distance, km	*Stable F, sec/m* *U = 3 sec* *H = 500*	*Unstable B, sec/m* *U = 5 sec* *H = 1000*
10	7×10^{-6}	7×10^{-8}
100	7×10^{-7}	1.0×10^{-8}
1000	7×10^{-8}	1.4×10^{-9}

TABLE 4

AMOUNTS OF ^{3}He NEEDED TO BE RELEASED IN ORDER TO RESULT IN AIR CONCENTRATIONS OF 1 PPT. TRACER MATERIAL IS ASSUMED TO BE RELEASED OVER A PERIOD EQUAL TO THE TRAVEL TIME FROM SOURCE TO RECEPTOR

- 11 -

	Stable		*Unstable*	
Distance, kn	*Travel Time, hr*	*Total Released*	*Travel Time, hr*	*Total Rele*
10	0.93	0.06 (.45 L)	0.56	3.6 (2
100	9.3	6.0 (45 L)	5.6	300.0 (2
"1000"	93.0	"600" (4500 L)	56.	"19,000" (

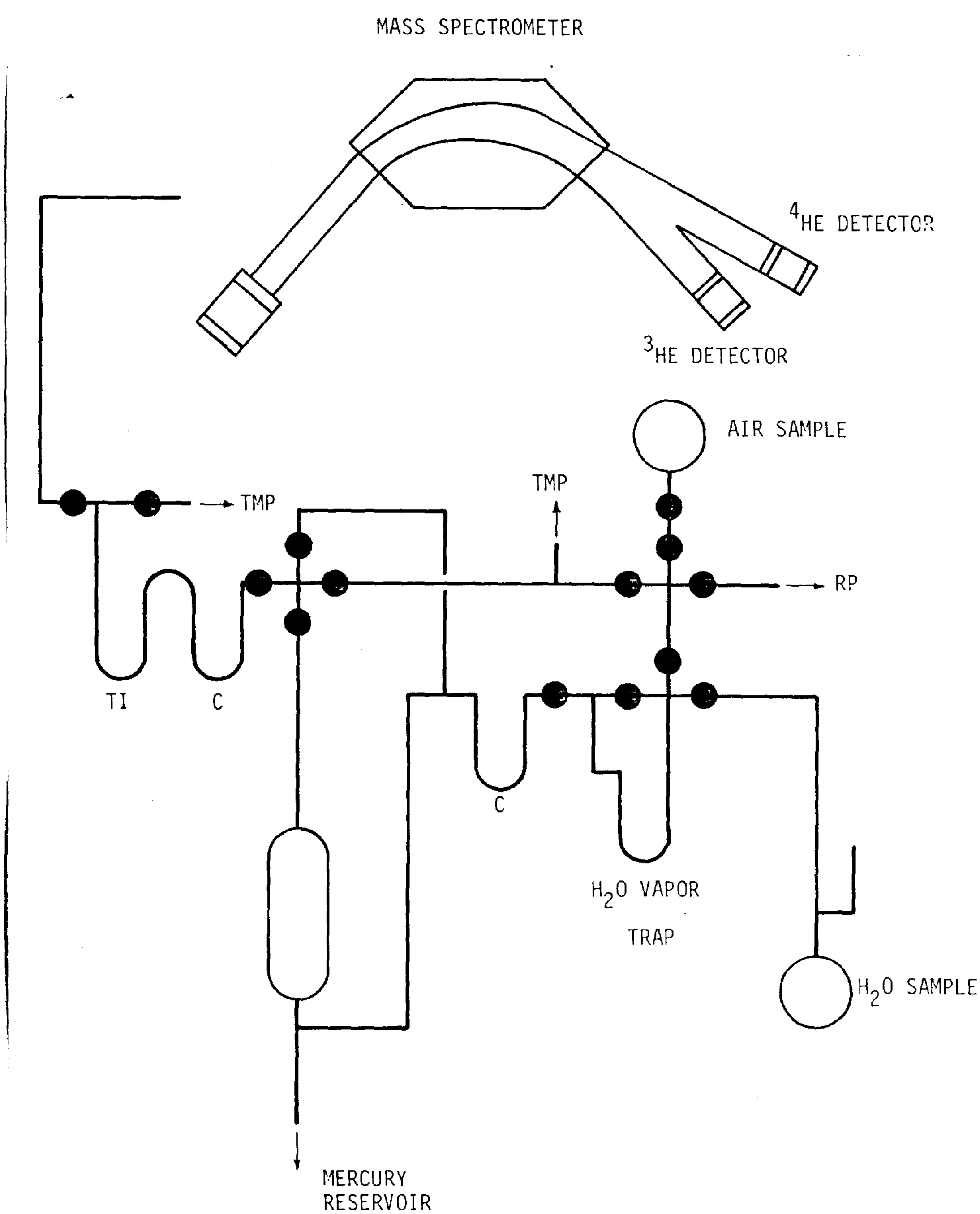

FIGURE 1. Mass Spectrometer and Sample Inlet System