An Inert Gas Tracer System for Monitoring the Real-Time History of a Diffusing Plume or Puff[1]

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ABSTRACT

A brief description is given of the Hanford inert gas tracer system employed in atmospheric diffusion studies. Among the advantages of the system are the detailed histories of concentration generated simultaneously at 64 field positions, and the ability to disperse instantaneous point sources (puffs) as well as longer duration releases (plumes). Concentration measurements are made to a distance of 800 m from the source.

Sample data resulting from a puff and a plume release are given. A minor amount of data analysis follows. Mean effective transport heights resulting from the ground-level puff release are found to increase from 0.9 m at 200 m from the source to 1.7 m at a distance of 800 m. For the continuous plume, corresponding effective transport heights from a release 1 m above the surface were found to be 1.2 m and 1.6 m. For the puff, the ratio of σ_x to σ_y was found to be 3.9 at 200 m from the source, and 4.2 at 800 m.

1. Introduction

A field tracer system has been developed which has the capability of monitoring in real time the history of a diffusing plume or puff of the inert radioactive gas krypton-85. Thirteen releases of this noble gas tracer have been made. Although these releases were made primarily to check the feasibility and response of a prototype field system, the data generated were of such high quality and in such unusual detail that some quantitative analysis has been made. The intent here is to briefly describe the field system, to present samples of the data generated, and to make known the availability of these data.

Nickola *et al.* (1970) have assembled the diffusion and associated meteorological data for the 13 field releases into a volume available from the Clearinghouse for Federal Scientific and Technical Information. A description of the tracer system—with emphasis on instrumentation—has been published by Ludwick *et al.* (1968). Nickola and Ludwick (1968) estimated the depletion of a plume of fluorescent particles by comparing this plume to a simultaneously emitted plume of krypton-85. Ramsdell and Hinds (1969) employed the krypton data in an examination of peak-to-mean concentration ratios within a plume.

Among the advantages of an inert gas tracer is that the tracer will have minimum interaction with structures or vegetation. Neither will it react with other atmospheric constituents. Further, the subject system permits generation of either an instantaneous puff or of a continuous plume of an atmospheric tracer and provides for the simultaneous measurement in real time of downwind concentrations at many locations.

2. Field system and experimental technique

In the completed prototype tests, a plume or puff of tracer was released at the center of a sampling grid. In the case of the plumes, the source was a pressurized gas cylinder from which krypton-85 was released at a controlled rate of ~1 curie (Ci) min^{-1} for periods of 10–20 min. The effective source height was ~1 m. Puffs were generated by crushing quartz ampules containing the tracer in a guillotine-like device (Fig. 1). The gas in each ampule had been sealed at near atmospheric pressure so

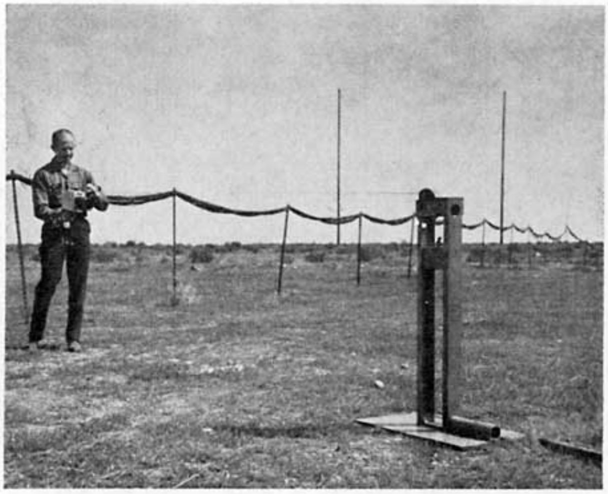

FIG. 1. Guillotine employed in puff generation.

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FIG. 2. Ground-level field detector.

as to minimize the initial volume of the "instantaneous point" source. Vials were crushed at ground level.

As the plume or puff was carried downwind, it was detected by a series of 64 field samplers located on concentric arcs 200 and 800 m from the source point. Twenty of these detectors, 1.5 m above the ground, were spaced at 2° intervals on each of the sampling arcs. Fig. 2 shows a protective cap being removed from one of these detectors. The remaining 24 samplers were mounted on six towers, three towers on each arc. These instrumented towers were spaced at 16° intervals. If the 1.5 m "ground-level" samplers are included, the 200 m arc towers were instrumented at 0.8, 1.5, 3.0, 6.1 and 11 m. At 800 m, detectors were at elevations of 0.8, 1.5, 4.5, 11 and 21 m.

The sensor employed to detect the 0.69 MeV (max) beta particles associated with the krypton-85 was a halogen-quenched Geiger-Müller tube. The detectors were calibrated by supporting several in turn inside a large meteorological balloon into which a known amount of krypton-85 and air were injected. The balloon was expanded until the radius of the sphere was greater than the range of the krypton beta particle. The calibration appropriate for the Geiger tubes checked was 9.7 counts $\text{sec}^{-1}\cdot(\mu\text{Ci})^{-1}\ \text{m}^{-3}$. During the calibration procedure, it was determined that 90% of the counts registered by the detector were generated within a radius of 1 m of the detector, and more than 99% originated within a radius of 1.5 m.

Information from these detectors was relayed by coaxial cables to a 4096 address memory. The memory was programmed to accept data simultaneously from the 64 detectors for 64 time increments. A time-interval selector permitted automatic advance of the stepping process at a slow or fast rate through the 64 time increments. The time-increment selector permitted counting intervals of 1.2, 2.4, 4.8 or 38.4 sec. The specific time interval selected was determined by the length of time the plume or puff was expected to take to clear the sampling grid. When information accumulation completely filled the memory, the data were read onto magnetic tape and the memory was cleared. The time interval required for dump and reactivation was about 40 sec.

The central electronics were housed in a temperature-controlled trailer about 100 m from the source point. A coaxial cable carried high voltage from this central location to a field detector and returned the beta-initiated pulses from the detector to the central station. Bundles of these cables are visible in both Figs. 1 and 2. The bundle in Fig. 1 incorporates the total 64 cables which lead to the trailer, which is off the photograph to the left. The bundles were suspended on metal stakes primarily to avoid difficulties with desert rodents. After removal of the protective caps from field detectors, all data collection functions could be handled from the trailer by a single individual.

The area directly upwind of the source was less than perfect in terms of the clear fetch desired in an ideal diffusion study. A flat-bed trailer about 6 m in length was parked about 4 m upwind of the source location. Several boxlike pieces of apparatus were spaced on the trailer. Overall, a lattice-like cross section of 8–10 m^2 was presented to the wind approaching the source and undoubtedly caused some wake effects in the vicinity of the source.

Terrain on the diffusion grid was quite flat. Vegetation was primarily sagebrush and steppe grasses.

3. Examples of field data

Two specific field experiments will now be examined in some detail. The first was a continuous release of about 20 min at the rate of 1.0 Ci min^{-1}, and the second release was a puff of 10 Ci. The continuous plume was generated between the hours of 0512:22 and 0532:13 on 8 November 1967. The puff was released at 0602:00 on the same morning. Meteorological measurements were made on towers near the source during both releases. The atmosphere was slightly stable during the entire period of testing. A temperature inversion (for the layer 0.9–15 m) of 0.5C was observed during the period of the continuous plume release and transport. This inversion increased to 0.9C during puff release and transport. The wind speed at 1.5 m remained near 2.6 m sec^{-1} during the continuous release, but dropped to about 1.6 m sec^{-1} during the period of puff diffusion.

Fig. 3 presents a real-time history of concentration for the continuous plume. The numbers plotted in the body of the figure are net counts per second generated by each ground-level (1.5 m elevation) detector. (A total of 2.0 counts sec^{-1} of background has been subtracted from the plotted values.) The net count rate is directly proportional to krypton concentration. The left half of the figure pertains to the 200 m arc and the right half presents 800 m data. Horizontally across the

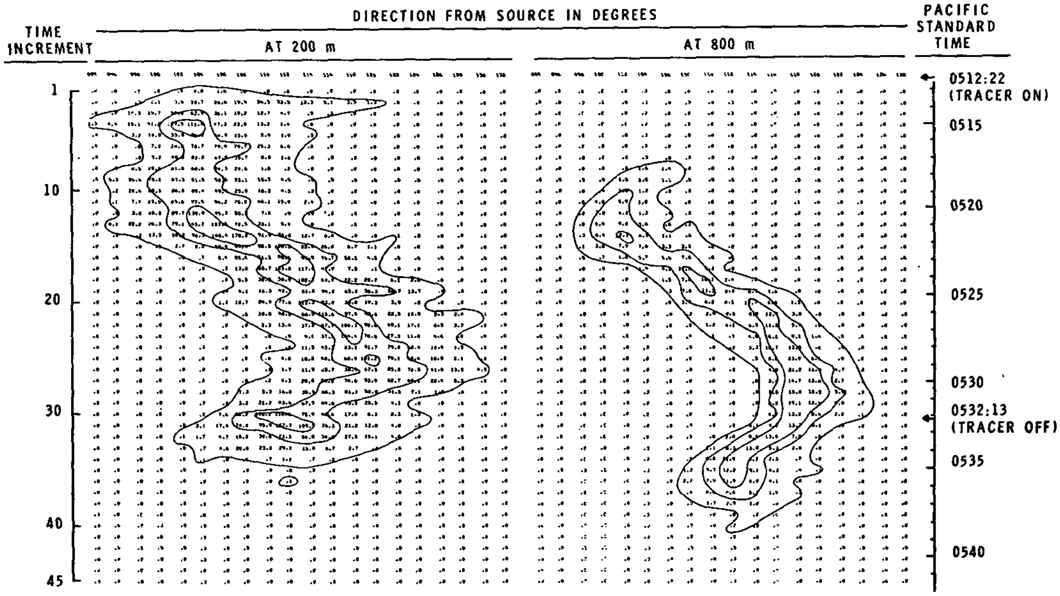

Fig. 3. Ground-level distribution of relative concentration with respect to time and to direction from source. The tracer was released continuously for 20 min.

top of the figure, the detector locations are listed with respect to their direction from the source. The vertical axis represents time. Listed vertically along the left of the figures are the sequentially numbered discrete time increments during which pulses from each field detector were integrated. Duration of the time increment during this experiment was 38.4 sec. (Time lost between sampling periods was negligible—on the order of a few milliseconds.) Pacific Standard Time is referenced along the right margin of the figure.

The body of Fig. 3 is actually a photograph of the printer output resulting from electronic data processing of raw Geiger tube counts. Isopleths were added by hand. Although there are calibration constants appropriate for each detector, a common calibration was employed in the prototype tests. In a few instances, tubes with relatively high background noise level were observed; however, the individual detector data were generally consistent and directly intercomparable.

Fig. 4 presents cross-wind sums of relative concentration vs time for the release isoplethed in Fig. 3. Note that for this layer near the ground-level samplers, the flux passing 200 m builds up rapidly, attains an equilibrium-like status, and drops off at about the same rate. At 800 m, the buildup to equilibrium is slower than the decay. These 800 m data are the opposite to that which one might intuitively expect. In contrast, all of the puff data—where time resolution is in greater detail—show a more rapid buildup of flux than the subsequent decay.

Turning now to the puff release, the dwell increment employed during monitoring was 4.8 sec as opposed to the 38.4 sec used with the continuous release. The high sampling frequency resulted in a much more detailed history of the puff as it passed the sampling arcs. Unfortunately, the puff had not completely cleared the arcs at the time the 64 sampling increments were exhausted. In fact, it required stepping through the 64 time increments twice and a portion of a third time before the krypton puff cleared the 800 m arc. Presentation of all these data in the format of Fig. 3 is not feasible in this report. However, Fig. 5 presents a typed and isoplethed representation of the puff data in a format similar to that given in Fig. 3 for the continuous

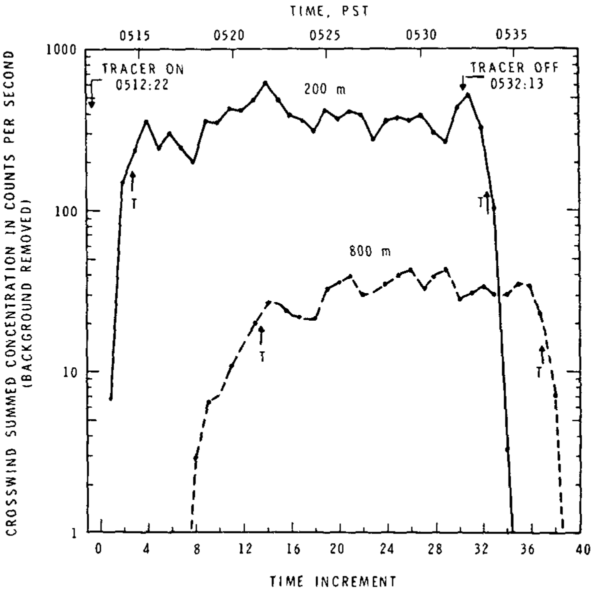

Fig. 4. Cross-wind sum of relative concentration vs time for continuous release.

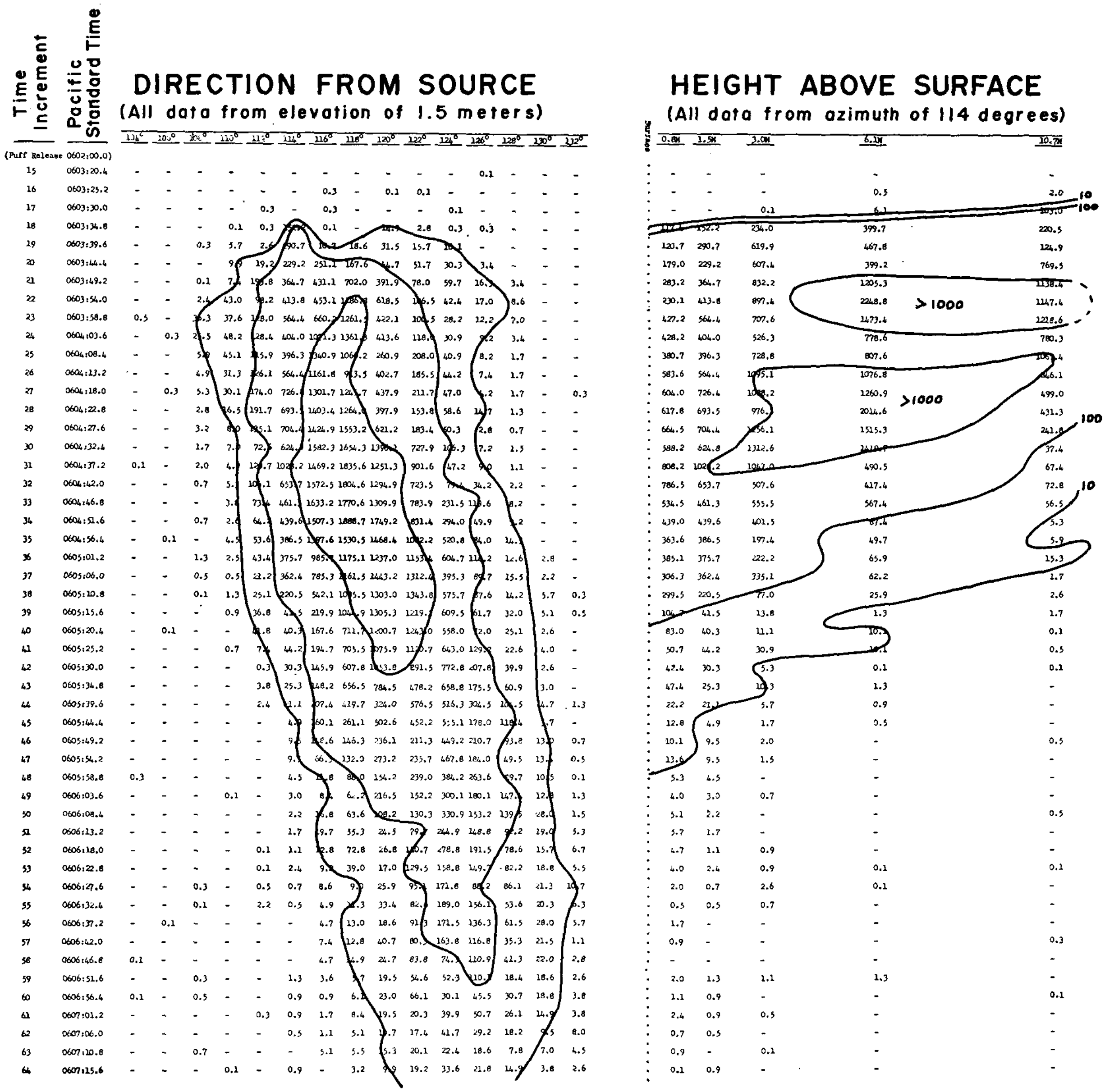

FIG. 5. Ground-level and vertical distributions of relative concentration following puff release.

plume. No 800 m data are included, and only above background data for the first 64 time increments are detailed. This figure further contrasts with Fig. 3 in that a vertical profile of concentration with time is given in the right-hand portion of the figure. These data were obtained from the tower at an azimuth of 114° from the source. The tower data point out that despite the inversion existing during diffusion of the surface-released puff, high concentrations of the tracer resulted above the 10.7 m (topmost) sampler on the tower.

Fig. 6 presents the cross-wind sums of relative concentration vs time for the subject puff. All summed rates >1 count $\sec^{-1}$ are plotted. The fluxes at both 200 and 800 m build up relatively rapidly and drop off more slowly. It is interesting to note that this instantaneous point source had grown to the extent that it required more than 6 min to pass the 200 m arc and more than 10 min to pass the 800 m arc.

4. Examples of data analysis

Although detailed analysis of data is not within the scope of this paper, a few precursory examples of the analysis opportunities offered by the real-time nature of the data follow.

It is possible to compute an effective transport wind speed necessary to bring the leading and trailing edges of the puff or plume to the sampling arcs. If a transport

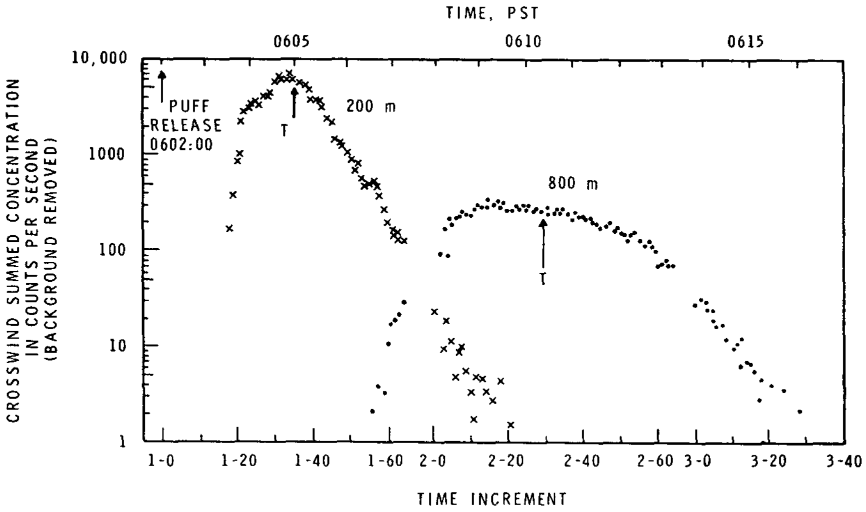

FIG. 6. Cross-wind sum of relative concentration vs time for puff release.

time can be selected as representative of an entire puff, then an accompanying effective "mean" transport speed can be computed here also. Choosing of a generally representative speed for a plume involves more subjectivity than is the case with a puff. In any event, the computed effective transport speeds can be related to wind speed profiles measured over appropriate time increments on nearby towers, and effective transport heights for beginning, "mean," and trailing portions of a puff or plume can be determined. The computed speeds and heights are applicable to samples measured at the 1.5 m elevation. This level is likely *not* the centroid of the diffusing krypton cloud. Table 1 presents the effective transport speeds u_t and height h_t applicable to the discussed plume or puff. For the puff, the speeds and heights result from the computation of the mean time for the cross-wind summed concentrations. These points in time are noted by T on Fig. 6. For the continuous plume, two T values are selected at each arc. The first T value is subjectively defined as the time at which the cross-wind summed concentration first reaches a value equal to the lowest cross-wind sum for the period when no leading edge or trailing edge plume effects are in evidence. The second T for the continuous plume is determined in a manner analogous to the first T except that it occurs as the concentration starts to drop. These T times are indicated on Fig. 4. The values of effective speed and height presented as representative values for the continuous plume are derived from means of the two T times at each arc. The less precise time definition and the more arbitrary definitions associated with the plume make the plume data in Table 1 less significant than those from the puff.

The summed cross-wind distribution of tracer as a function of time, shown for the puff on Fig. 6, may be combined with the effective transport speeds of Table 1 to compute σ_x values for the puff. At 200 m, σ_x is 47 m, and at 800 m it is 154 m. Although the data are not shown, a summation of counts by azimuth permits a calculation of σ_y. The σ_y values at 200 and 800 m, respectively, are 12 and 37 m. Ratios of σ_x to σ_y of 3.9 at 200 m and 4.2 at 800 m indicate a continuing elongation of the puff.

5. Planned improvement

Although this tracer system supplies relatively great detail, especially at the 1.5 m elevation, the 16° interval between towers results in too few measurements to adequately define cross-wind concentration distributions above the 1.5 m height. An anticipated expansion of the system includes instrumenting of towers spaced at 8° intervals to heights of 27 m at a distance of 200 m,

TABLE 1. Effective transport speeds and heights.

Type source	Distance from source (m)	Leading edge		Mean or representative value		Trailing edge	
		u_t (m sec^{-1})	h_t (m)	u_t, (m sec^{-1})	h_t (m)	u_t (m sec^{-1})	h_t (m)
Puff	200	2.1	5.2	1.1	0.9	0.4	0.2
Puff	800	2.9	9.4	1.6	1.7	1.0	0.4
Continuous	200	~3.3	6.6	2.3	1.2	1.3	0.3
Continuous	800	~2.6	2.5	1.6	1.6	2.5	1.2

and to heights of 47 m at 800 m. Another improvement planned for the krypton-85 system is the addition of a second memory unit. Detector signals can then be read into one memory while the second unit is dumping stored data to magnetic tape. This procedure will permit uninterrupted sampling with short sampling increments for both puffs and plumes.

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