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ENVIRONMENTAL EFFECTS OF A TRITIUM GAS RELEASE FROM THE SAVANNAH RIVER PLANT ON DECEMBER 31, 1975

W. R. JACOBSEN

SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA 29801

PREPARED FOR THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION UNDER CONTRACT AT(07-2)-1

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ABSTRACT

At 10:00 p.m. EST on December 31, 1975, 182,000 Ci of tritium gas was released within about 1.5 min from a tritium processing facility at the Savannah River Plant. The release was caused by the failure of a vacuum gage and was exhausted to the atmosphere by way of a 200-ft-high stack. Winds averaging 20 mph carried the tritium offplant toward the east. Calculations indicate that the puff passed out to sea about 35 miles north of Charleston, South Carolina, about 7 hr after the release occurred. Samples from the facility exhaust system indicated that 99.4% of the tritium was in elemental form and 0.6% was in the more biologically active oxide (water) form. The maximum potential dose to a person (from inhalation and skin absorption) at the puff centerline on the plant boundary was calculated to be 0.014 mrem, or about 0.01% of the annual dose received from natural radioactivity. The integrated dose to the population under the release path was calculated to be 0.2 man-rem before the tritium passed out to sea.

Over 300 environmental samples were collected and analyzed following the release. These samples included air moisture, atmospheric hydrogen, vegetation, soil, surface water, milk, and human urine. Positive results were obtained in some onplant and plant perimeter samples; these results aided in confirming the close-in puff trajectory. Tritium concentrations in nearly all samples taken beyond the plant perimeter fell within normal ranges; no urine samples indicated any tritium uptakes as a result of the release. Two milk samples did indicate a measurable tritium uptake; the maximum potential dose to an individual drinking this milk was calculated to be about 0.1 mrem.

Because calculated doses from assumed exposure to the tritium are low and analyses of environmental samples indicated no significant accumulation of tritium, it is concluded that no significant environmental effects resulted from the December 31, 1975, tritium release.

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Appendices

ENVIRONMENTAL EFFECTS OF A TRITIUM GAS RELEASE FROM THE SAVANNAH RIVER PLANT ON DECEMBER 31, 1975

INTRODUCTION

At 10:00 p.m. EST on December 31, 1975, 182,000 Ci of tritium gas was released within about 1.5 min from a tritium processing facility at the Savannah River Plant.

Tritium (T) is a radioactive isotope of hydrogen (H) with an atomic mass of 3 that decays with a radiological half-life of 12.33 years to ^{3}He. The maximum energy of the beta particle emitted during decay is 0.0186 MeV; the average energy is about 0.006 MeV. The concentration guides[1,2] for exposure of members of the public to tritium in air and water are:

HTO or T_2O: Basis - 500 mrem whole body dose per year
Annual Average Concentration Guide
Inhalation and skin absorption (air) - 0.2 μCi/m^3
Ingestion (water) - 3×10^{-3} μCi/ml

HT or T_2: Basis - 3 rem inert skin dose per year
Annual Average Concentration Guide
Submersion (air) - 40 μCi/m^3

These concentration guides apply to individual members of the public exposed to the highest annual average concentration and should be reduced to one-third of the values shown when applied to a suitable sample of the population.[1]

Tritium is produced at the Savannah River Plant (SRP) both as a desired product by irradiation of lithium and as an activation product by neutron capture in the heavy water (D_2O) used to moderate and cool the production reactors. In addition, a small amount of tritium is formed as a result of uranium fission. Normal releases from the reactors and tritium processing facilities result from small leaks and infrequent exposure of normally closed systems to ventilation air. A brief discussion of SRP tritium releases and their causes is given in Reference 3; a more extensive review of tritium processes in Federal facilities is provided in Reference 4.

In 1975, routine releases of tritium to the atmosphere from SRP operations (as measured by tritium monitors at the points of release) totaled 306,000 Ci (not including the December 31, 1975, release). About 262,000 Ci was in the oxide form (HTO, DTO, T_2O)*, and about 44,000 Ci was in the molecular form (HT, DT, T_2)*. The average daily release was then 720 Ci as HTO and 120 Ci as Ht. Samplers capable of collecting tritium in both forms are located at six of the plant perimeter monitoring stations. For the period January through September 1975, the average concentrations measured were 8.3×10^{-5} µCi/m^3 as HTO, and 3.6×10^{-5} µCi/m^3 as HT.

In the December 31, 1975, release, the 182,000 Ci of total tritium discharged to the atmosphere was about 200 times the average daily total tritium release from SRP; however, the more biologically active component, HTO, was only about 1.5 times the average daily HTO release.

THE RELEASE INCIDENT

On December 31, 1975 at 10:00 p.m., 182,000 Ci of tritium gas was released from a tritium processing facility at SRP when a vacuum gage in a process sampling system failed. The release was promptly detected by tritium monitoring systems (Kanne chambers). The rate of release as indicated by the stack monitor is shown in Figure 1. About 90% of the tritium was released over a period of 1.5 min and was mixed with building ventilation air, which was being discharged from the 200-ft exhaust stack at a rate of 135,000 ft^3/min (a total volume of 202,500 ft^3 during the 1.5-min period). The average tritium concentration in the exhaust stack air over the 1.5-min was about 3.2×10^7 µCi/m^3 or about 12 ppm by volume. At this very dilute volumetric concentration, the discharged tritium would be expected to behave as a gas with no appreciable buoyancy, and would be dispersed as a part of the natural atmospheric constituents with the prevailing winds. Because of the short duration and high dilution of the release, it could be treated as a simple "puff" for meteorological calculations.

FORM OF TRITIUM RELEASED

Samplers capable of collecting separate samples of elemental tritium gas and tritium oxide (tritiated water) were installed in the tritium facilities in August 1974. These samplers (Appendix A) are connected to the exhaust systems and measure the proportion of released tritium that is in either of the physical forms. The total quantity of released tritium is measured by the regular Kanne chamber monitoring system used in tritium facilities.

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* HTO and HT will be used in this report to represent tritium in any of the possible oxide or molecular forms.

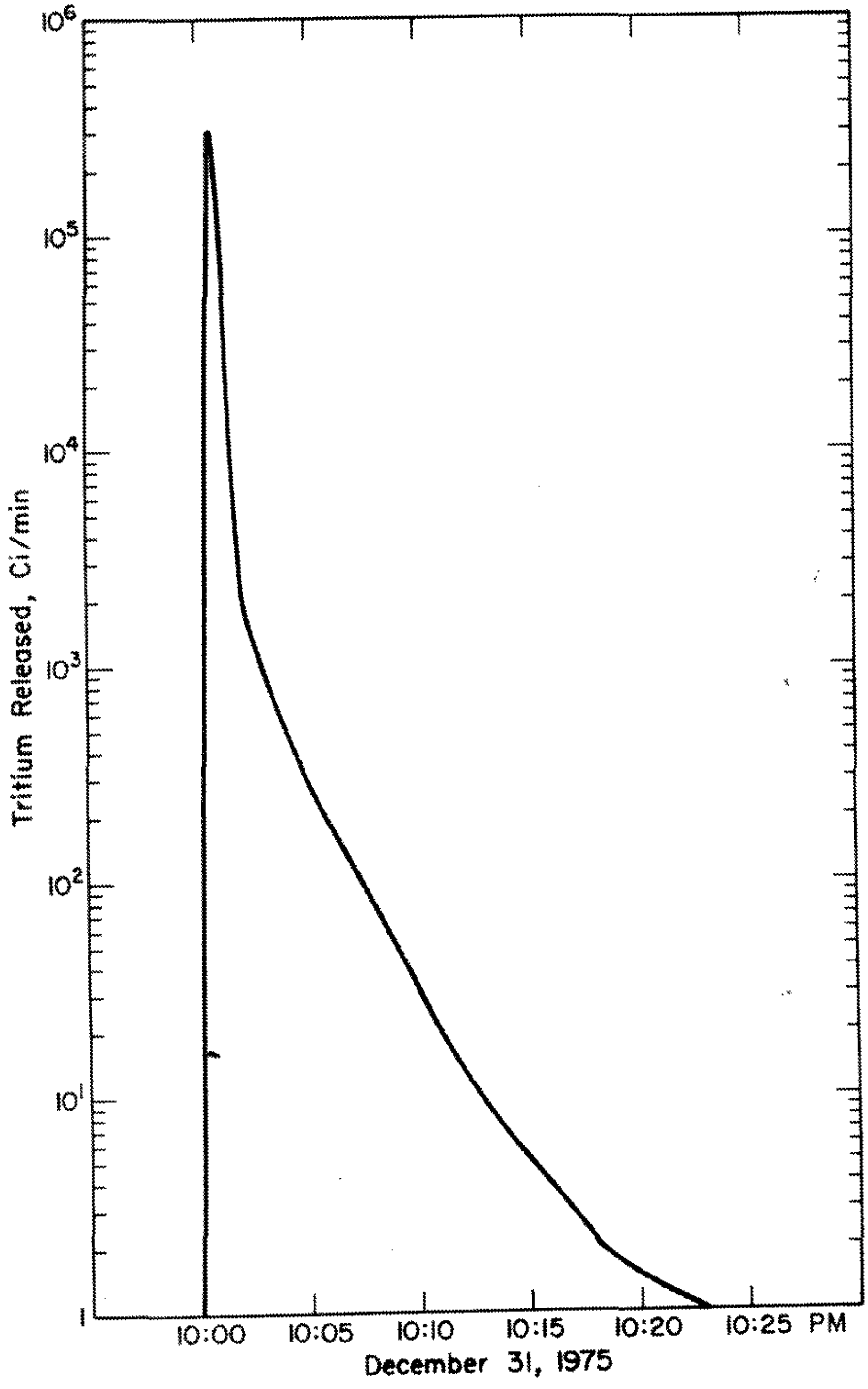


FIGURE 1. Rate of Tritium Release Shown by Exhaust Stack Monitor (Redrawn from original recording chart)

Analyses of the samplers following the release indicated that 99.4% (181,000 Ci) of the tritium was released in the molecular form, with 0.6% (about 1,100 Ci) in the oxide or water form.

Tritium released in the form of the elemental gas can undergo oxidation in the atmosphere to form water ($2T_2 + O_2 \rightleftarrows 2\ T_2O$), and it can exchange with normal hydrogen present in atmospheric moisture ($T_2 + H_2O \rightleftarrows HTO + HT$). Both the oxidation and isotopic exchange reactions of tritium are induced by or influenced by the beta radiation of tritium, and the reaction rates are dependent on the tritium concentration. The reaction rates are also strongly influenced by metal catalysts. For example, experimental data[5] indicate that tritium gas at an initial concentration of 2×10^7 μCi/m^3 in humid air would be converted to tritiated water with a half-time of 700 days; in the presence of a metal catalyst (surface to volume ratio of 0.36 to 1), the reaction half-time would be approximately 60 hr.

When tritium is released to the atmosphere, it is quickly diluted by several orders of magnitude. After release from the stack, the tritium gas is so diluted in the atmosphere that its beta radiation becomes essentially ineffective as an initiator of the conversion reaction. At that point, the tritium can be considered to be part of the total hydrogen in the troposphere as far as conversion to water is concerned. The estimated lifetime of hydrogen in the troposphere is between 2 and 10 years,[6-9] with the higher value appearing to be the most reliable.

In the December 31, 1975 release, the oxide observed in the stack sample was probably formed immediately after the gas leaked. Only during this short period were tritium concentrations sufficiently high to result in conversion to the oxide. In the stack, the highest concentration occurred during the first 1.5 min, which included 90% of the release. The tritium was diluted in 200,000 ft^3 of air to an average concentration of 3×10^7 μCi/m^3. During rapid passage through the stack at this concentration, less than 10^{-4}% of the gas would be converted to the oxide (assuming no metal catalyst was present; even if present, the amount converted would be 0.03% or less). After discharge from the stack, the gas was diluted to ∿100 μCi/m^3 at the plant boundary 0.5 hr after release and to ∿3 μCi/m^3 at the coast 7 hr after release. At these low concentrations, the 0.6% HTO value measured in the stack can be assumed to persist throughout the transit of the puff to the coast.

METEOROLOGICAL CONDITIONS AND ESTIMATES OF DOWNWIND CONCENTRATIONS

Meteorological conditions at the time of the tritium release and for several hours thereafter were categorized as Pasquill type[10] D (neutral stability) with quite strong winds initially from the west and later from the west-northwest. The wind speed at the time of the release was 10 m/sec (22 mph) and slowly decreased to 8 m/sec (19 mph) 5 hr after release time. The wind direction initially was from 270-272°, turning to 275° 3 hr after release, then to 280°, and finally to 300° by 9 hr after release time. Figure 2 shows the estimated trajectory of the tritium puff during the first 8 hr following the release; by this time, the puff had moved out to sea.

Puff Trajectory

The circles in Figure 2 represent the calculated puff dimensions at various times after release; 91% of the released tritium was calculated to be within the circular boundaries at the indicated times. Maximum instantaneous tritium concentrations under the puff centerline at ground level were calculated as described in Appendix B. Calculations were performed both for the total tritium release and for that portion of the tritium that was released as the oxidized form. Figure 3 gives the concentrations for total tritium as a function of time, and Figure 4 gives the same information for the tritium in the oxide form. The concentration guides in these figures are for annual averages whereas the exposure time to the puff was approximately one hour.

The change in slope of the curves in Figures 3 and 4 at about 1 hr is caused by the changes in wind speed with time and by vertical mixing with a mixing depth of 400 m. This mixing depth, or confining "lid," causes the centerline concentration to decrease less rapidly with time after vertical mixing is complete through this layer.

The trajectory of the puff was estimated from available meteorological data. Figures 5, 6, and 7 each depict the surface wind flow over SRP and downwind of SRP. Figure 5 shows the wind flow at the time of the release, Figure 6 at 2:00 a.m. (4 hr after release), and Figure 7 at 5:00 a.m. (7 hr after release). At 5:00 a.m., the puff went out to sea. The wind arrows plotted just east of Augusta, Georgia, are 62-m (200-ft) data interpolated from instrumentation on a nearby TV tower; the one arrow just east-southeast of Augusta represents the best value determined from seven 62-m towers located at the operational areas of SRP. The data plotted at locations other than the local towers are from National Weather Service Stations located at larger airports and are surface wind data taken at heights from 4 to 10 m (15 to 35 ft) above ground.

During the time the release was traveling over South Carolina, the skies were clear, and there was no precipitation occurring in or near the state. The puff was estimated (Figure 2) to take a slightly more southerly path after 3:00 a.m., although the 5:00 a.m. wind flow from the Charleston surface data (Figure 7) still showed westerly or slightly south of westerly flow. The southerly path was more likely because by 3:00 a.m. to 5:00 a.m. the puff would have been sufficiently well-mixed vertically that the primary steering would be by flow at 100 to 500 m above ground rather than by surface flow. The SRP towers and TV tower (with wind instruments up to 1,100 ft) indicated that flow at higher altitudes turned from 270° to 290° to 300°. The same change in wind directions was evidenced from upper air data taken at 7:00 a.m. at Charleston Airport.

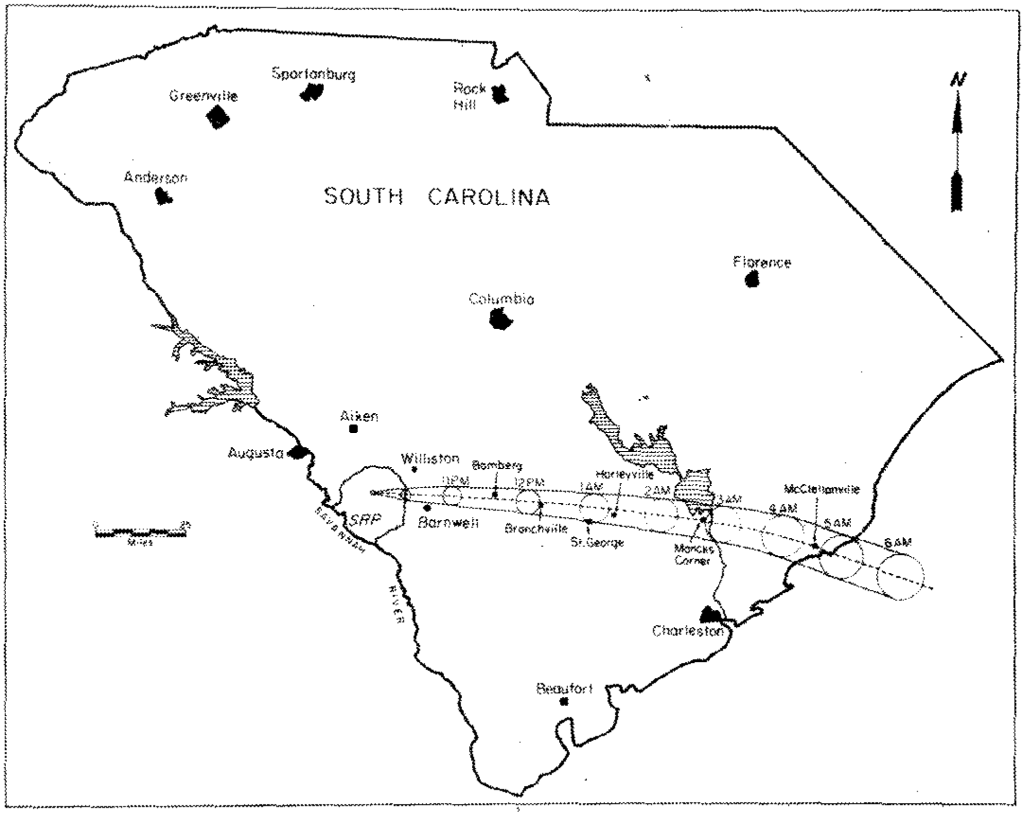


FIGURE 2. Estimated Puff Trajectory for December 31, 1975 Tritium Release

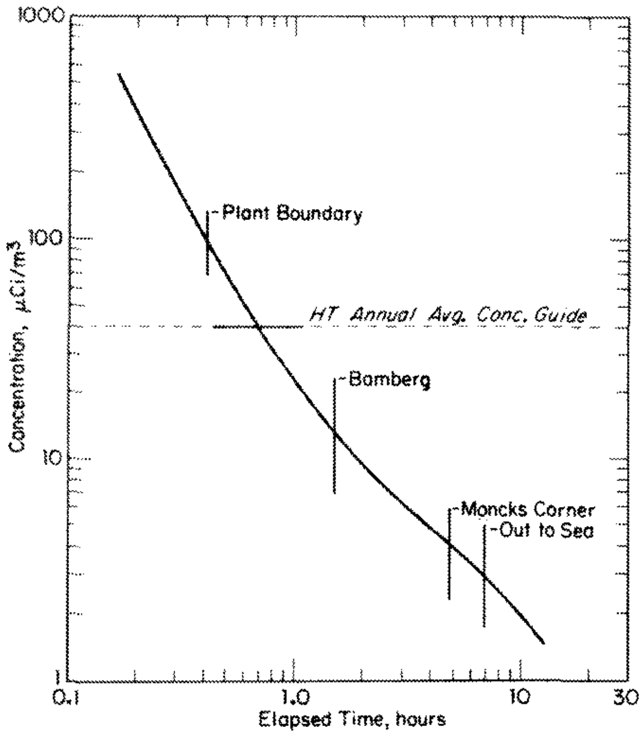


FIGURE 3. Puff Centerline Concentration, Total Tritium

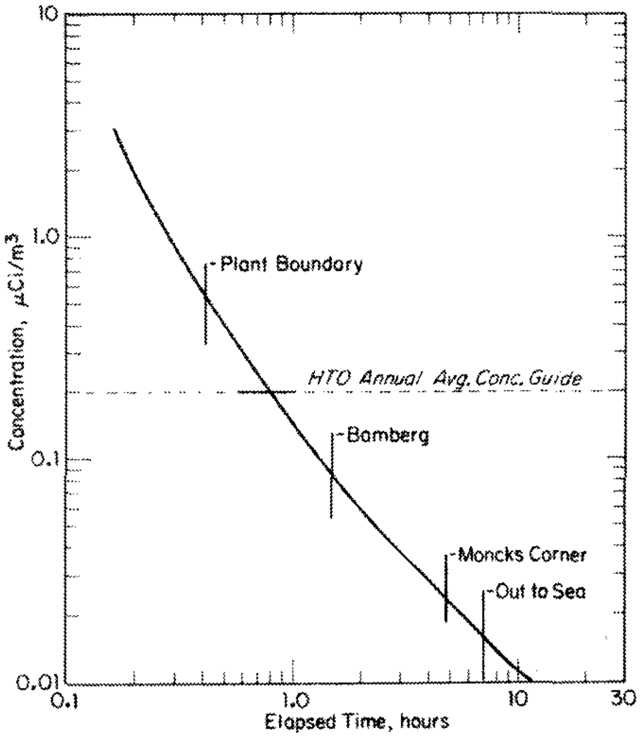


FIGURE 4. Puff Centerline Concentration, HTO

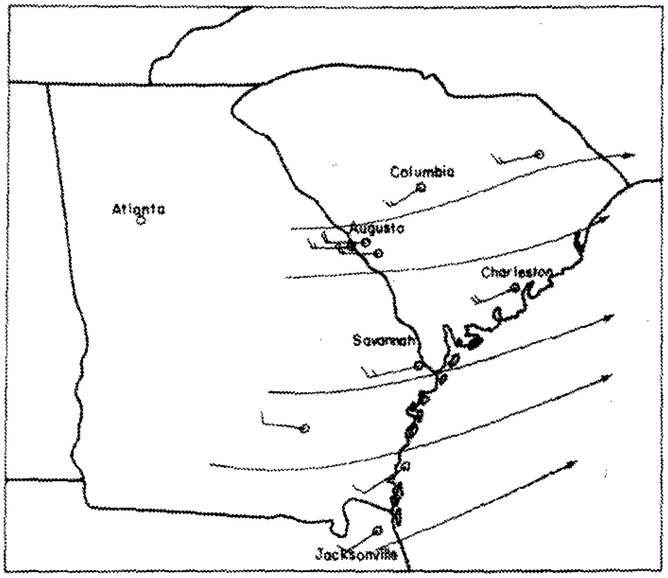


FIGURE 5. Surface Winds for December 31, 1975, 10:00 PM

A full barb is 5 m/sec (10 knots), and a half barb is 2.5 m/sec (5 knots). The shaft indicates the direction from which the wind is blowing.

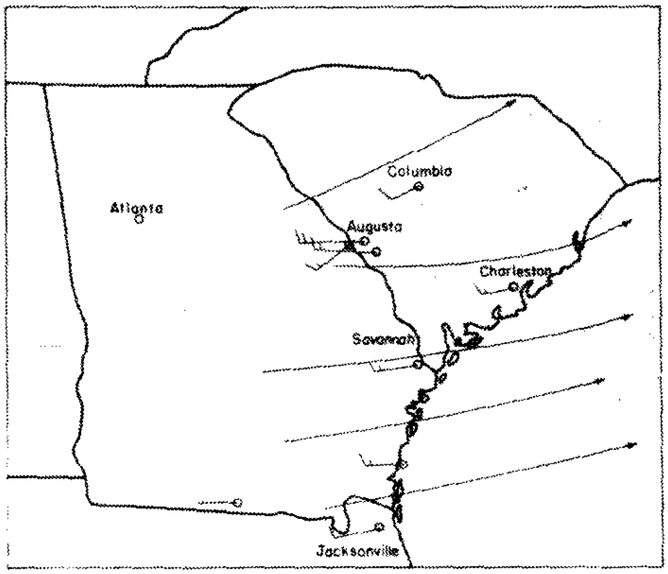


FIGURE 6. Surface Winds for January 1, 1976, 2:00 AM

A full barb is 5 m/sec (10 knots), and a half barb is 2.5 m/sec (5 knots). The shaft indicates the direction from which the wind is blowing.

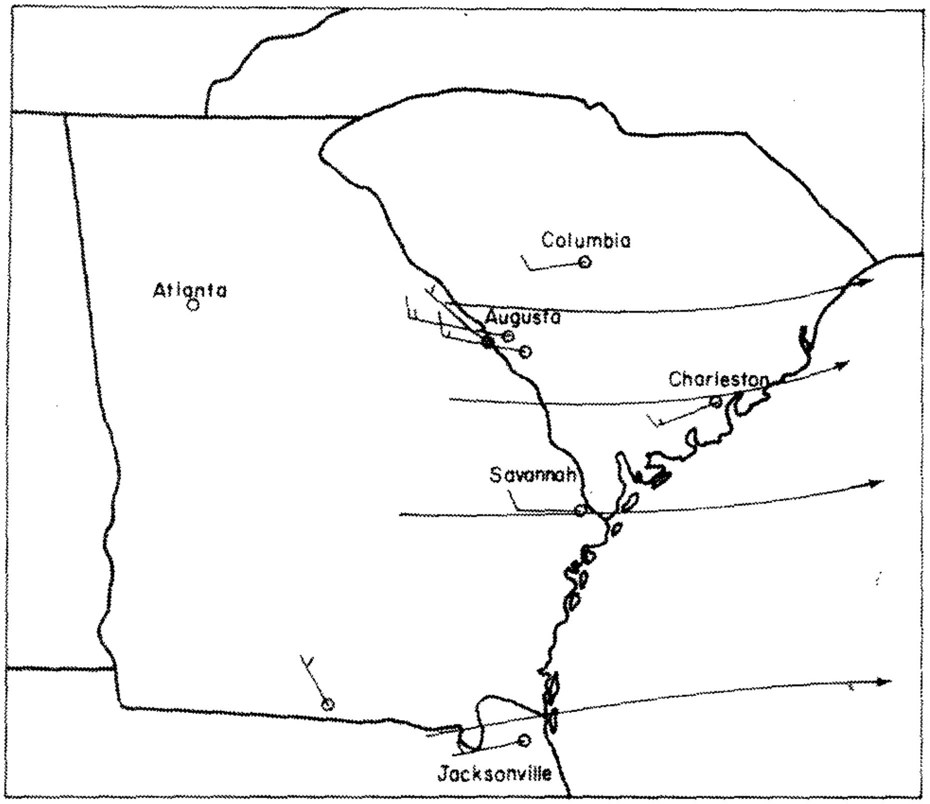


FIGURE 7. Surface Winds for January 1, 1976, 5:00 AM

A full barb is 5 m/sec (10 knots), and a half barb is 2.5 m/sec (5 knots). The shaft indicates the direction from which the wind is blowing.

Evaluations of Puff Trajectory

The puff trajectory was evaluated on January 1, 1976, to provide a basis for performing extensive environmental sampling. The trajectory calculated at this time was somewhat to the south of the one depicted in Figure 2. This was because the initial evaluation used the higher level winds and wind data from the 200-ft meteorological tower near the tritium processing facility. More-detailed data evaluation showed that the lower level winds would control the initial 4 to 5 hr of the release path. It was also shown that there was a system calibration error in the tower sensor such that wind direction from that sensor was approximately 15° in error in the clockwise direction. The revised trajectory agrees very well with the maximum tritium activity found in vegetation and soil in the sampling near the plant boundary.

OFFPLANT DOSE CALCULATIONS

The low-energy beta particle emitted by tritium during decay will penetrate human tissue only 0.013 cm. As an elemental gas, tritium constitutes little hazard because the weak beta is completely attenuated (absorbed) in the inert external skin layer (epidermis), and because only 0.004% of the elemental tritium inspired is converted to the oxide and retained in the body.[11] Therefore, the dose from the December 31, 1975 release was calculated to come from the 0.6% HTO present. The concentration guide for tritium oxide is several hundred times less than that of the elemental gas form because almost all of the oxide form (water vapor) that is inhaled is absorbed in the lungs and enters the body water pool, and all body tissues are exposed. In addition, almost as much tritium oxide is absorbed through the skin as is absorbed during inhalation.[12]

One of the key factors affecting the dose from HTO is its biological half-life for retention in the body. The average biological half-life of tritium for SRP employees has been measured to be 9.6 days.[13] Values as high as 19 days have been reported elsewhere.[14] The value used by the International Commission on Radiological Protection[12] for calculating concentration guides is 12 days and is the value used for dosimetry calculations in this report.

The maximum integral concentration of tritium (as HTO) at ground level in the centerline of the puff at the plant boundary was calculated to be 1.0×10^{-4}(Ci-sec)/m^3. A person exposed to this integral concentration would receive a whole body dose of 0.014 mrem through inhalation and skin absorption of HTO. Doses at other locations along the puff trajectory are given in Figure 8. The average dose to an individual at the boundary from the 306,000 Ci of tritium released in 1975 (assuming 100% oxide) was about 0.5 mrem.

The dose to the population in the path of the tritium between SRP and the coast was about 0.2 man-rem (see Appendix B). The population dose for the initial evaluation of the trajectory, which included Charleston, S. C., was about 1 man-rem. The dose commitment to the population living within 100 km of SRP was 96 man-rem from 1975 tritium releases to the atmosphere.

The maximum tritium concentration measured in offplant samples was 9 pCi/ml in a milk sample. The dose to an infant from consumption of milk initially containing 9 pCi/ml and declining in concentration with a half-time of five and one-half days[15] (assuming a consumption rate of 1 liter of milk per day) would be about 0.1 mrem.

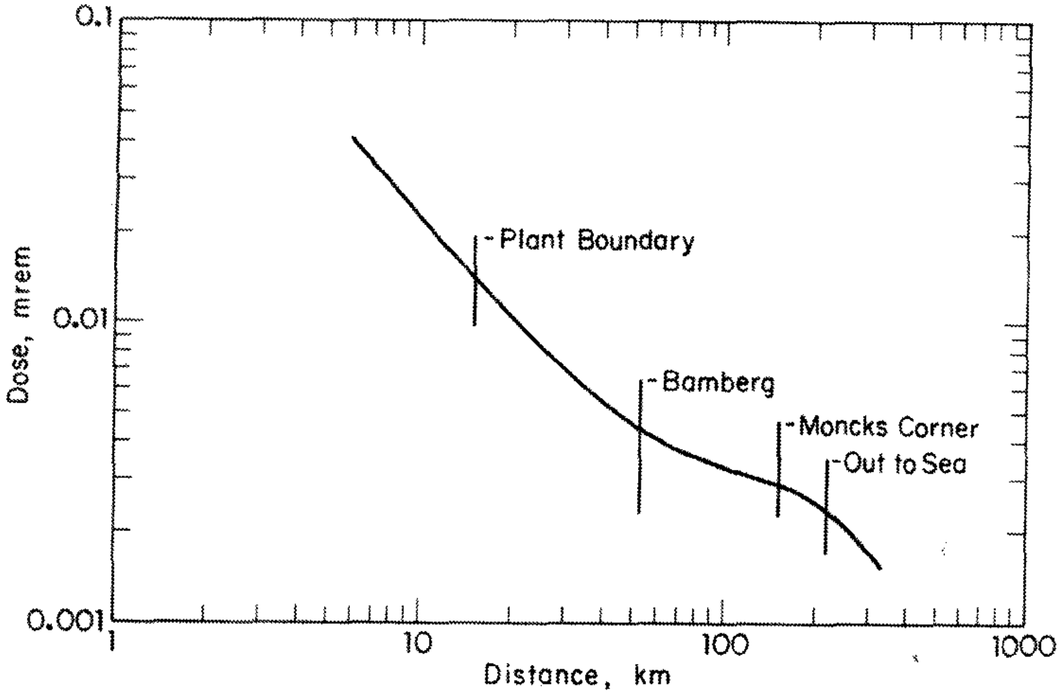


FIGURE 8. Potential Radiation Exposure to Individuals along Centerline Path of December 31, 1975, Tritium Release

These doses compare to an annual average dose from natural radiation sources of 120 mrem to individuals and 84,000 man-rem to the 700,000 persons living within 100 km of SRP.

The world-wide population dose commitments resulting from tritium releases can be estimated using the EPA model[16] for distribution, uptake, and dose conversion factors. The EPA model assumes dilution of the tritium in the circulating waters of the northern hemisphere and that the exposed population is 80% of the world population (1976 world population ∿4 × 10^9). The addition of 1100 Ci of HTO to the atmosphere would result in a population dose of about 0.7 man-rem using the EPA model.

The slow conversion of HT to HTO discussed previously would permit the radioactive decay of about one-third of the tritium released in the molecular form rather than conversion to the oxide. The 181,000 Ci released as HT would then contribute about 121,000 Ci to the northern hemisphere inventory, with a resultant population dose of 76 man-rem (∿0.00002 mrem per person).

Comparison of these concentrations and doses with those from the only other comparable tritium release from SRP (that of May 2 1974) is given in Appendix C.

AIR MONITORING IMMEDIATELY FOLLOWING THE RELEASE

Tritium monitors in the ventilation system of the facility where the release occurred alarmed within a few seconds of each other at about 10:00 p.m., immediately following the gage failure. Air monitors in nearby buildings showed no increase in tritium activity during or immediately following the release. Surveys made outside of the buildings with portable instruments with a lower limit of sensitivity of 10 $\mu Ci/m^3$ showed no detectable tritium concentrations. These measurements indicated that the release was quickly dispersed from the immediate area as a result of the release height (200-ft stack) and the high velocity of prevailing winds. It was determined that the puff would be offplant before measuring teams could intercept it; plans were made to dispatch monitoring teams downstate.

ENVIRONMENTAL SAMPLING PROGRAM

Information on the path of a tritium release and the resultant dose-to-man can be obtained by sampling of the air, water, soil, and vegetation. Air sampling is most effective while the puff or plume is passing by the sampling location; water, soil, and vegetation sampling is most effective following passage of the release.

Tritium oxide can be transferred from the atmosphere to the water, soil, and vegetation by rainout and exchange of HTO with vegetation and soil moisture. Conversion of molecular tritium to the oxide form by soil micro-organisms and higher plants is also possible, but deposition by this mechanism is small.

There was no precipitation occurring at the time of the December 31 release or anywhere within the path of the release until it had gone out to sea. Thus, no rainout of the tritium occurred in the path.

The tritium content of water, soil, and vegetation was expected to be limited because the conditions during the release period were such that little exchange or conversion would take place. The high wind speed caused the tritium puff to move so rapidly that the exposure time of the water, soil, and vegetation to the puff was quite short. The cool conditions during the night of the release (surface temperatures varying between 50 and 39°F) decreased the metabolic activity of the micro-organisms in the soil and vegetation and minimized the conversion of molecular tritium. Vegetation would not exchange tritium oxide rapidly because of the closure of leaf stomatas at night.

Onplant and Plant Perimeter Sampling

Samples of vegetation and soil taken on January 1 and 2 on SRP property and at off-plant locations near the site boundary were useful in confirming the puff trajectory. Locations and sample results are shown in Figures 9 and 10. In particular, the soil samples along SRP Road 8, containing 186 and 242 pCi/ml H_2O, and the vegetation samples from Highway 21 just east of the plant, containing 92 and 27 pCi/ml H_2O, indicated a narrow puff diameter, and a path almost due east of the release point. These samples corroborated the correction made in the original trajectory predicted from meteorological data. The only other sample showing significant tritium assimilation was a vegetation sample taken just east of H Area; this sample contained 687 pCi/ml H_2O. Other onplant vegetation and soil samples fell within the range detected during routine sampling, 2-200 pCi/ml H_2O.

Thirty urine samples from workers in the tritium processing facility and adjacent areas showed no personnel uptakes from the release; all samples were less than 1 μCi/l. Analytical data for all bioassay samples are given in Appendix D.

Offplant Sampling

Two sampling teams were dispatched between 12:30 and 1:00 a.m. on January 1. Their routes and the locations where vegetation and water samples were taken are shown in Figure 11; sample data is included in Figure 12. Although some samples showed detectable tritium concentrations, these concentrations were within the normal variations observed in routine surveys; none were sufficiently high to indicate any significant tritium absorption by water or assimilation in vegetative growth.

Air concentrations were also measured with portable tritium survey instruments with a lower limit of sensitivity of 10 $\mu Ci/m^3$. No tritium was detected. Figure 11 shows the times the teams reached various locations for sampling. As shown in Figure 3, tritium in the puff centerline was calculated to be above the detection limit only for about 2 hr following the release, or until the time the puff was passing between Bamberg, South Carolina, and Branchville, South Carolina (Figure 11). The team on the northern route did not reach Bamberg until about 1:30 a.m. Thus, no positive air sampling results would have been expected. On the other hand, because all vegetation and water samples were taken after the estimated puff arrival, these samples should have shown positive results if any significant assimilation occurred.

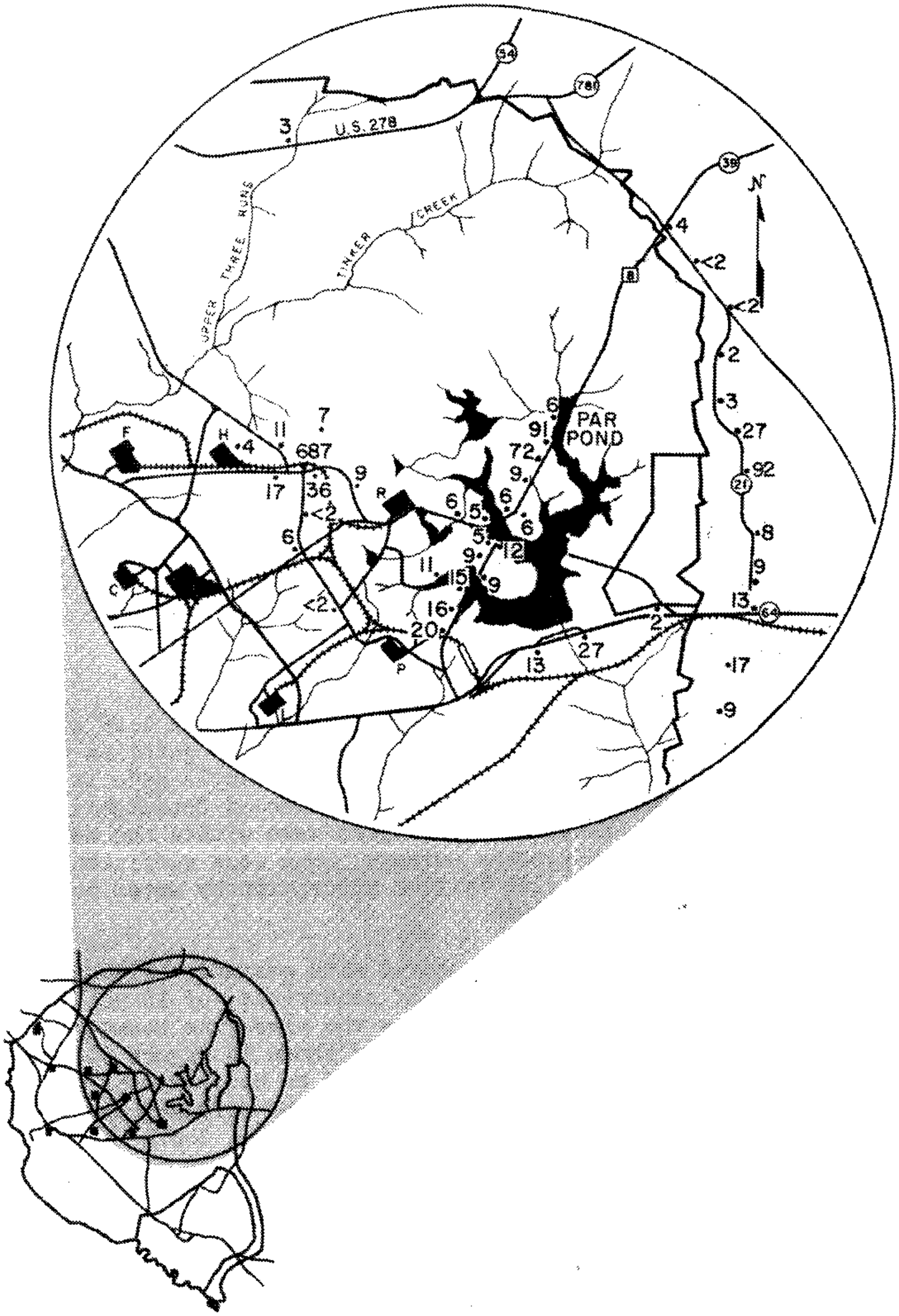


FIGURE 9. Tritium in Vegetation on January 1-2, 1976, pCi/mℓ H_2O

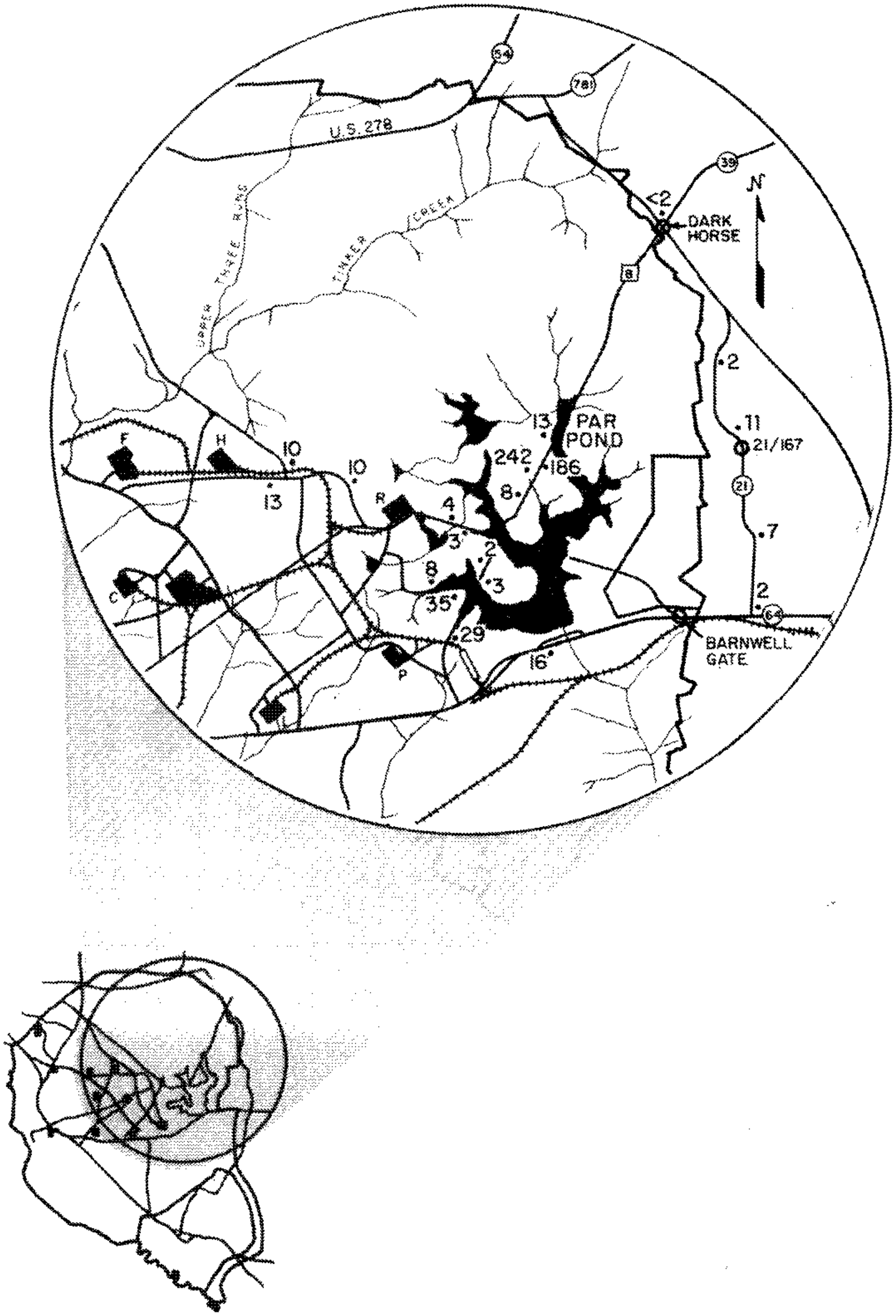


FIGURE 10. Tritium in Soil on January 1-2, 1976, pCi/mℓ H_2O

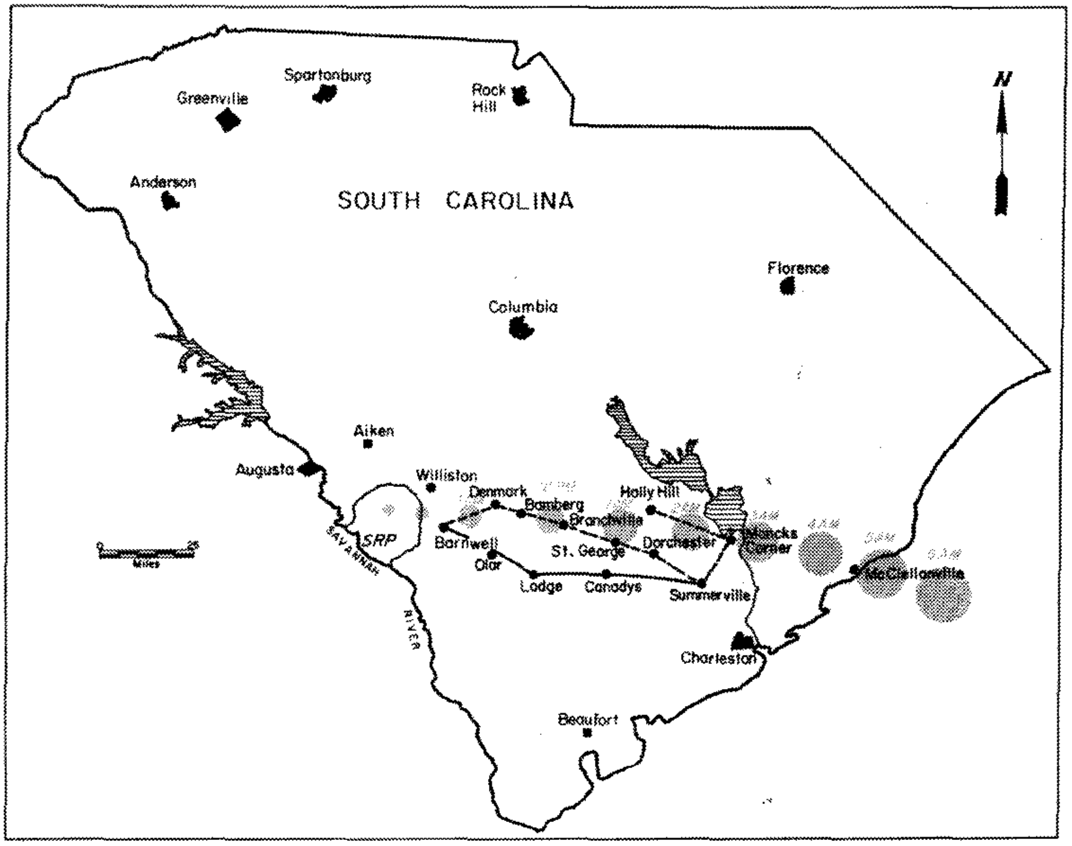


FIGURE 11. Early Sampling Routes (Left SRP about 12:50 AM)

--- North route to Summerville
—— South route to Summerville

Sampling Team Arrival Times

South Route (——)	
Olar	1:30 AM
Lodge	1:55 AM
Canadys	2:20 AM
Summerville	3:20 AM

North Route (---)	
Denmark	1:20 AM
Bamberg	1:30 AM
Dorchester	2:25 AM
Summerville	3:00 AM
Moncks Corner	3:30 AM
Holly Hill	4:30 AM

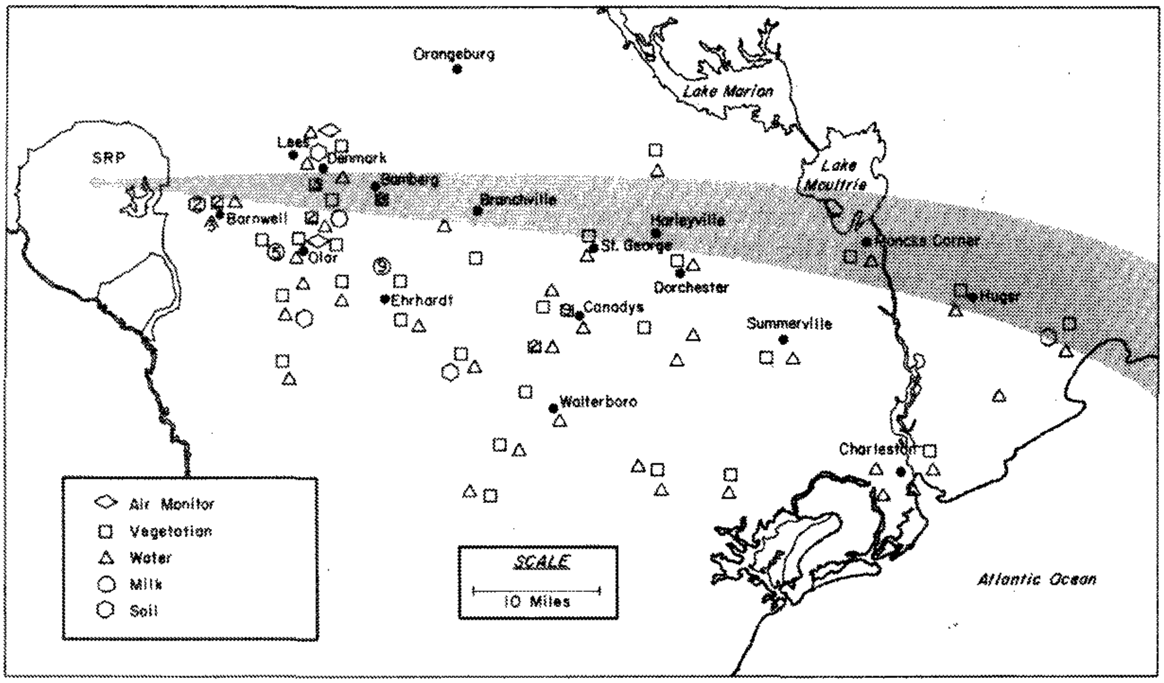


FIGURE 12. Tritium in Environmental Samples on January 1-2, 1976, pCi/mℓ H_2O (SRP to Coast). (Results are <2pCi/mℓ unless indicated.)

On January 1 and 2, additional samples were obtained between Barnwell, South Carolina, and the coast, using the January 1 estimate of the puff trajectory and concentrating on the area toward Charleston. Figure 12 shows the locations of samples taken and the concentrations of tritium found in the samples. This sampling program included air moisture, atmospheric hydrogen, bioassay (urine) samples from potentially exposed people, pine needles, leaves and other vegetation, milk, surface water, and soil.

Air Moisture

Permanently installed air samplers onplant, at the plant boundary, and on a 25-mile radius around the plant are equipped with silica gel samplers to collect air moisture for subsequent laboratory measurement of the tritium oxide concentration. These measurements normally represent a two-week sampling period.

Tritium oxide concentrations at the two plant boundary locations closest to the puff trajectory (21/167 and Barnwell Gate on Figure 10) were 4×10^{-5} and 6×10^{-5} $\mu Ci/m^3$ for the period 12-23-75 to 1-2-76. Concentrations at plant boundary locations averaged 10^{-4} $\mu Ci/m^3$ during 1975. These results reflect the fact that less than 1% of the release was in the form of HTO and that the rapid movement of the puff past the monitoring stations resulted in a short residence time relative to the total sampling period.

Concentrations at the 25-mile stations at Lees, South Carolina, and Olar, South Carolina (Figure 12) were 10^{-5} $\mu Ci/m^3$ for the period 12-23-75 to 1-8-76. The average concentration at these stations for 1975 was 6×10^{-5} $\mu Ci/m^3$.

Vegetation and soil analyses indicated a narrow diameter of the puff trajectory (Figures 9 and 10); the 25-mile stations are slightly outside this path. Because of their location and the high ratio of total sample exposure time to exposure time during the puff transit, these samplers would not have been expected to show significantly elevated HTO concentrations.

Tritium Forms

Samplers capable of collecting samples of elemental tritium gas and tritium oxide were installed at six of the perimeter monitoring stations in June 1974 to collect data on the composition of SRP tritium releases. These samplers were in addition to the previously described silica gel samplers that have been used for perimeter tritium oxide monitoring since 1960. The forms samplers did not show atmospheric molecular or oxide concentrations above those observed during normal operations. This result also indicates that the plume width was narrow and passed undetected between the nearest stations with forms samplers (Dark Horse and Barnwell Gate on Figure 10).

Vegetation

Fourteen vegetation samples were taken near public roads bordering the plant boundary; twelve of these had tritium concentrations greater than the sensitivity of the analyses (2 pCi/ml H_2O). The positive results ranged from 2 to 92 pCi/ml H_2O. Sample locations and analytical results are shown in Figure 9. Resamples at 7 of these locations on January 6 showed 43 pCi/ml H_2O near the same location that was 92 pCi/ml on January 1; the remainder were ≤ 2 pCi/ml. Routine vegetation samples from plant perimeter locations in 1975 ranged from <2 to 200 pCi tritium/ml H_2O. The use of these samples in confirming the puff trajectory was discussed previously.

Of the 33 offplant vegetation samples from locations further distant than the ones described above, only six had tritium concentrations greater than the sensitivity of the analyses (2 pCi/ml H_2O). These six ranged from 2 to 9 pCi/ml; 1975 data for samples near the 25-mile monitoring stations ranged from <2 to 70 pCi/ml.

Surface Water

One of the 38 offplant surface water samples showed concentrations of 3 pCi/ml; the remaining concentrations were less than the sensitivity of analysis (2 pCi/ml).

Soil

Four of the five soil samples taken near the plant boundary were above the detection limit of 2 pCi/ml H_2O; these ranged from 2 to 11 pCi/ml. The sample locations and results are shown in Figure 10.

All nine offplant soil samples from locations further distant than the ones described above, were at or below the sensitivity of analysis (2 pCi/ml H_2O).

Milk

Four milk samples were collected from farms and dairies on January 5, 1976. Two samples contained tritium concentrations greater than the detection limit, one at 9 pCi/ml and the other at 5 pCi/ml. 1975 data for milk samples collected in the vicinity of SRP ranged from <2 to 3 pCi/ml.

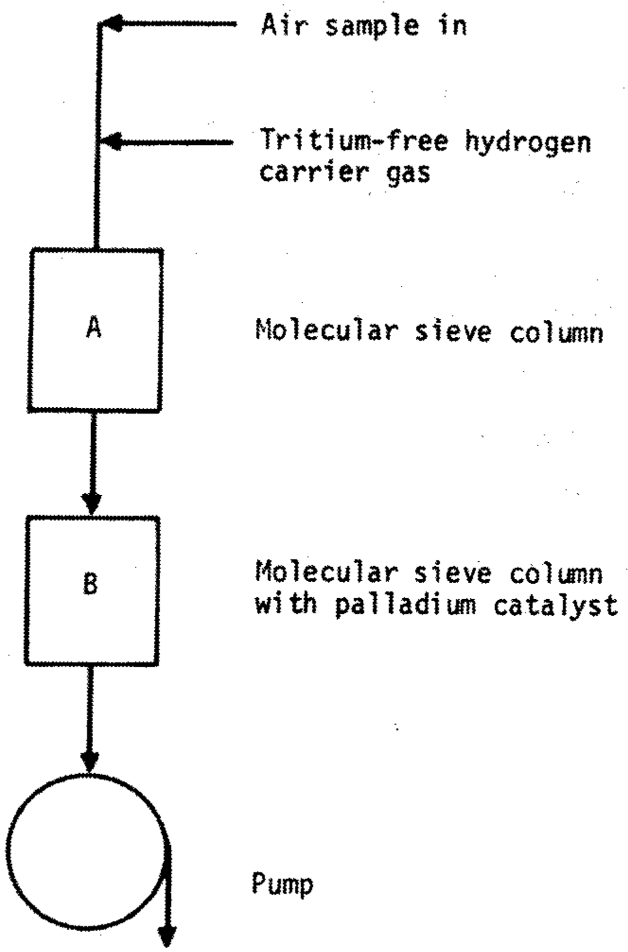
Bioassay

Urine samples were obtained from plant employees and members of the public living between SRP and the coast. All of the 81 samples contained less than 1 μCi of tritium per liter (the lower limit of detection). Sampling locations are given in Appendix D.

Conclusion

With the possible exception of two milk samples, the off-plant sampling program detected no conclusive evidence of tritium assimilation by physical or biological systems in the environment.

APPENDIX A. TRITIUM FORMS SAMPLER



Method of Operation

1. The gas stream to be sampled is drawn into the sampler and mixed with tritium-free hydrogen carrier gas.

2. Air moisture (H_2O and HTO) is collected on molecular sieve in Column A.

3. Elemental tritium gas (HT and T_2) mixed with the tritium-free hydrogen carrier gas passes through Column A.

4. The hydrogen gas and tritium is converted to oxide form by a palladium catalyst in Column B. The water so formed is collected on molecular sieve in Column B.

5. Moisture is distilled from Columns A and B and collected separately.

6. Moisture samples A and B are analyzed for tritium content separately. Sample A represents tritium that was in the form of oxide in air, and Sample B represents tritium that was in the form of elemental gas in air.

7. Tritium content of water samples A and B are related to tritium concentration in air by measurements of the following, taken at the time of sampling:

    - Absolute humidity
    - Air sampler flow rate
    - Length of sampling time
    - Flow rate of tritium-free hydrogen carrier gas

APPENDIX B. CONCENTRATION AND DOSE CALCULATIONS

Downwind Concentration Calculations for an Instantaneous Source (puff release)[17]

The computer code described in this appendix uses meteorological tower data to calculate concentrations from accidental or short-term pollutant releases to the atmosphere. This code has small storage and computer time requirements and has been adapted for a mini-computer to provide a means for obtaining an estimate of the expected concentrations in real time.

The computer code was written primarily to determine the pollutant concentrations resulting from an accidental release of a sufficiently short duration that the cloud can be considered to be a puff. The equation for an instantaneous point source (a puff) is:

$$\chi = \frac{2Q}{(2\pi)^{3/2}\sigma_{yI}\sigma_{xI}\sigma_{zI}} \exp. - \tfrac{1}{2} \left[\frac{(x-\bar{u}t)^2}{\sigma^2_{xI}} + \frac{y^2}{\sigma^2_{yI}} + \frac{h^2}{\sigma^2_{zI}} \right] \quad (1)$$

Equation 1 is used to provide an estimate of the concentration χ at any position (x, y, z) resulting from a point source at height h. The distance x is measured along the axis of the plume, y is measured perpendicular to the plume, and z is measured above ground level. The source term Q is the total release. The parameters in Equation 1 that are functions of meteorological variables are determined from data from towers located near the operating areas. The instruments are at a height of 62 m above the ground, which is the height of most stacks at SRP. The wind speed $\bar{u}$ is an arithmetic mean over an averaging time of one hour.

The dispersion coefficients (σ_{xI}, σ_{yI}, and σ_{zI}) are evaluated using a relationship of the form

$$\sigma^2_{rI} = 2K_r\ t \quad (2)$$

where r is measured along the x, y, and z direction, σ^2_{rI} is the variance of concentration for a puff along the r direction, K_r is the eddy diffusivity in the r direction, and t is elapsed time.[18]

For Fickian diffusion, the eddy diffusivity is constant with time and space. For most instances, vertical profiles of the eddy diffusivities can be used to estimate appropriate values for the three dispersion coefficients. Unfortunately, most atmospheric diffusion processes are not Fickian. Numerous comparisons of the above expressions with experimental data on diffusion in the atmosphere have shown that K varies systematically with time of travel, position, and scale of the diffusion process.[19] As a means of including this time and scale dependence of K in the simple calculation for puff diffusion, the relationship developed by Walton[20]for a time- and scale-dependent eddy diffusivity is used. This relationship is given by

$$K(t) = c_1 \, \varepsilon^{1/3} \, (\sigma_0^{2/3} + 2/3 \, c_2 \varepsilon^{1/3} t)^2 \qquad (3)$$

where c_1 and c_2 are constants of order unity, ε is the turbulent dissipation rate, and σ_0 is related to the initial size of the release in the r direction. In order to put restraints on the maximum value that the eddy diffusivities can obtain, Walton uses the following expression

$$K(t)' = \frac{K(t) \; K_{max}}{K(t) + K_{max}} \qquad (4)$$

where $K(t)'$ is the adjusted eddy diffusivity, K_{max} is the maximum expected eddy diffusivity, and $K(t)$ is the eddy diffusivity given by Equation 3.

The above relationships show that the dispersion coefficients and the eddy diffusivities can be expressed as a function of the single variable ε, which can be calculated from meteorological data obtained at each tower using the expression

$$\varepsilon = \frac{u_*^3 \; k}{z} \qquad (5)$$

where k is the Von Karman constant (0.4), z is the height above ground level, and u_* is the friction velocity defined by

$$u_* = (\overline{u'w'})^{\frac{1}{2}} \qquad (6)$$

An alternative expression based on empirical results by Crawford[21] gives ε as a function of wind speed u and height above ground

$$\varepsilon = \frac{300}{z} \times \left(\frac{u}{5}\right)^3 \tag{7}$$

where ε is in ergs/(g-sec), z is height above ground in m, and u is wind speed at height z in m/sec.

Radiation Dose Calculations

To calculate the radiation dose to an individual from a puff of tritium in the atmosphere, the concentration of the oxide form is calculated as described above, and the dose at the plume centerline is calculated according to the following formula:

$$\text{Dose} = 0.143 \, \frac{\pi}{2} \, \frac{\sigma_x}{\bar{u}} \, \chi_{HTO} \tag{8}$$

where:

0.143 = rem/(Ci-sec per m^3). (Dose factor for inhalation and skin absorption of HTO by an active man.)

σ_x = the standard deviation of the puff diameter in meters

$\bar{u}$ = the average wind during the time of the puff passage

χ_{HTO} = puff center concentration (maximum concentration at a given distance downwind of the release) of the tritium in the oxide form in appropriate concentration units (varies as a function of time).

In the December 31, 1975 release, the source terms that were used for the calculations were 182,000 Ci of total tritium and 1,092 Ci of tritium in the oxide form.

The term $\left(\frac{\pi}{2} \frac{\sigma_x}{\bar{u}} \chi_{H_2O}\right)$ in Equation 8 represents the integrated concentration to which an individual on the plume centerline is exposed in units of (Ci-sec)/m^3. Multiplication by 0.143 rem/(Ci-sec)/m^3 gives the exposure in dose units at various locations along the path of the release. These values are shown in Figure 8 as a function of distance from the point of release.

Perimeter Dose in December 31, 1975 Release

The point at which the December 31, 1975 release is estimated to have passed over the plant boundary is about 15 km due east from the release point. At this location, the time-integrated concentration of HTO was 1.0×10^{-4} (Ci-sec)/m^3, with a potential dose to an individual at that location of 0.014 mrem.

Population Dose in December 31, 1975 Release

The population dose was calculated by summing the product of integrated dose (determined as above for the perimeter dose) times the number of people exposed to that dose. Actual population data were used in 10-km increments along the path of the release with the corresponding integrated dose for those increments. The results of these calculations are shown below for 50-km increments.

Increment, km	*Population*	*Population Dose, man-rem*
0 - 50	6,300	0.042
50 - 100	11,640	0.045
100 - 150	18,680	0.057
150 - 210	4,500	0.012
0 - 210	41,100	0.156

A similar calculation for a trajectory that included the Charleston, South Carolina, metropolitan area resulted in a potential population dose of about 1 man-rem.

APPENDIX C. COMPARISON OF DOWNWIND CONCENTRATION AND DOSE WITH THE TRITIUM RELEASE OF MAY 2, 1974

The calculation of downwind tritium concentrations for the December 31, 1975 release was made using models improved over those which were used to analyze the data from the May 2, 1974 tritium release.[15] The original dose calculated for the May 2, 1974 release in Reference 15 from tritium in the oxide form (960 Ci) was 0.14 mrem. When this calculation is redone using the recently developed puff models (Appendix B), a dose of 0.016 mrem is obtained. It should be noted that the data given in Reference 15 for the oxide form tritium dose was calculated assuming a Pasquill Type D stability. Subsequent evaluations[22] have revealed that the conditions were more closely described by the Pasquill Type C category. When that category is used, the dilution factor would be 1.3×10^{-7} rather than the value for the D Type stability of 1×10^{-6} used in Reference 15. When using a Pasquill Type C category, the dose calculated for the May 2, 1974 event from the oxide form of tritium would be 0.018 mrem at the plant boundary (15 km from release point). For the December 31, 1975 release, the plant boundary value as shown in Figure 8 is 0.014 mrem.

APPENDIX D. HTO IN URINE

Location	*Number of People Analyzed*[a]
Onplant	
Plant employees	30
Offplant	
Plant employees living downwind or adjacent to the December 31, 1975 release path	
Barnwell	9
Hilda	1
Kline	1
Olar	4
Sycamore	1
Fairfax	1
Ehrhardt	11
Lodge	4
Islandton	3
Smoaks	5
Ruffin	2
Branchville	2
St. George	1
Walterboro	6
Ritter	1
Dorchester	1
South Carolina County Health Department Employees	
Allendale	6
Bamberg	7
Walterboro	4
Barnwell	3
Other Location	
Charleston	8
Total	112

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[a] All samples on and offplant were <1 μCi/ℓ.

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