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# GREATER CONFINEMENT DISPOSAL TEST AT THE NEVADA TEST SITE

## FINAL TECHNOLOGY REPORT

September 1988
Revised January 1989

Prepared by

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# ACKNOWLEDGEMENTS

The Greater Confinement Disposal Test (GCDT) was an operational research and technology demonstration project for disposal of high-specific-activity (HSA) wastes. The GCDT was conducted over a period of several years and its success is attributable to the many individuals who participated in its development. In particular, contributions made by Paul T. Dickman, R. Eric Williams, Mark C. Olson, Daniel A. McGrath, and David Kreamer who served as both technical contributors and principal investigators for many aspects of the GCDT should be noted. In addition, J. Robert Boland, Peter K. Fitzsimmons, and Bruce W. Church of the Department of Energy Nevada Operations Office (DOE/NV) should be recognized as the principal developers of the "greater confinement" disposal concept and were critical to establishment of GCDT and its acceptance as a method for "Greater Than Class C" waste disposal.

# ABSTRACT

The Greater Confinement Disposal Test (GCDT) was conducted at the Department of Energy's (DOE) Nevada Test Site (NTS) to demonstrate an alternative method for management of high-specific-activity (HSA) low-level waste. The GCDT was initially conceived as a method for managing small volumes of highly concentrated tritium wastes, which, due to their environmental mobility, are considered unsuitable for routine shallow land disposal. Later, the scope of the GCDT was increased to address a variety of other "problem" HSA wastes including isotope sources and thermal generating wastes.

The basic design for the GCDT evolved from a series of studies and assessments. Operational design objectives were to: (1) emplace the wastes at a depth sufficient to minimize or eliminate routine environmental transport mechanisms and intrusions scenarios, and (2) provide sufficient protection for operations personnel in the handling of HSA sources. To achieve both objectives, a large diameter borehole was selected.

The GCDT consisted of a borehole 3 meters (10 feet) in diameter and 36 meters (120 feet) deep, surrounded by nine monitoring holes at varying radii. The GCDT was instrumented for the measurement of temperature, moisture, and soil-gas content.

Over one million curies of HSA low-level wastes were emplaced in GCDT. This report reviews the development of the GCDT project and presents analyses of data collected.

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# GLOSSARY OF TERMS

| | |
|---|---|
| BCF | Bromochlorodifllouroethane |
| CFR | Code of Federal Regulations |
| DLLWMP | Defense Low-Level Waste Management Program |
| DOE | Department of Energy |
| Freon-13B1 | Bromotrifluoromethane |
| GCD | Greater Confinement Disposal |
| GCDT | Greater Confinement Disposal Test |
| GTCC | Greater Than Class C |
| HSA | High Specific Activity |
| LLW | Low-Level Waste |
| NRC | Nuclear Regulatory Commission |
| NTS | Nevada Test Site |
| RDAS | Remote Data Aquisition System |
| RWHS | Remote Waste Handling System |
| RSTC | Recirculation System Test Container |
| $SF_6$ | Sulfurhexafluoride |
| SLD | Shallow Land Disposal |
| STP | Shallow Test Plot |
| TCP | Thermocouple Psychrometer |
| TDAS | Tracer Diffusion Analytical System |

# 1.0 INTRODUCTION

The GCDT was an operational research and technology demonstration project for disposal of HSA wastes. The GCDT was conducted over a period of seven years and during a period when fundamental changes to low-level waste (LLW) disposal requirements and philosophy were occurring. The initial purpose of the GCDT was to develop a cost-effective method for disposing of low-level wastes which were operationally difficult to handle or which exceeded specific radionuclide concentration limits. This section provides a background on the development of greater confinement disposal concept and the initial considerations used in development of GCDT.

## 1.1 Development of the GCDT Concept

In 1978, DOE established the National Low-Level Waste Management Program (NLLWMP) which is now the Defense Low-Level Waste Management Program (DLLWMP) to address emerging technical and regulatory issues for generating and disposing of LLW. One of the early goals established by the DLLWMP was to seek improved methods for disposing of mobile radionuclide species, in particular, tritium.

The Nevada Test Site (NTS) was among the DOE disposal sites concerned with tritium wastes. The NTS was the disposal location for small volumes of concentrated tritium wastes from Mound Laboratories. These wastes were disposed in a conventional shallow land disposal (SLD) trench. Due to its high environmental mobility, minute quantities of tritium were soon detected at environmental monitoring stations located on the perimeters of the disposal site(1). While the amounts detected posed no hazards to workers or the environment, it was recognized that SLD did not provide sufficient confinement for these wastes. Similar problems with tritium wastes had been encountered at other DOE and commercially-operated LLW sites.

To address the issue of tritium waste disposal, DOE/NV proposed to develop an "intermediate depth" disposal project utilizing large diameter boreholes(2,3). The initial concept was to use a 3-meter (10-foot) diameter, 46-meter (150-foot) shaft. The thickness of the waste emplacement zone would vary based on the type and quantity of material disposed, but a minimum of 10-20 meters (30-60 feet) of backfill cover material would be used to seal the borehole. By staying below the 3-6 meter (10-20 feet) zone of active evapotranspiration, it was anticipated that the tritium wastes would be effectively confined from the major transport mechanism.

In March 1979, the Three Mile Island reactor accident occurred. One of the waste management issues brought to light by the accident was the problem with disposal of HSA cesium-137 and strontium-90 wastes contained within the submerged demineralizer and Epicor II filtration systems. Because of the accident, the ion exchange resins had become contaminated with levels of those nuclides which exceeded the limits for SLD and were therefore identified as a "new" category of HSA-LLW.

The obvious question faced by the DLLWMP was how much HSA-LLW were being produced at DOE facilities and how was it being managed? In October 1979, the DLLWMP requested that DOE/NV prepare a report on criteria necessary for development of an "intermediate" depth disposal facility(4). The report work scope was expanded to address analysis of DOE defense HSA-LLW streams and potential for use of boreholes at NTS for disposal of these wastes.

Concurrent with preparation of the report, technical meetings were held by DOE and the Nuclear Regulatory Commission (NRC) to assess the impacts and implementation requirements of the newly proposed Title 10 Code of Federal Regulations (CFR) Part 61(5,6). The regulations recommended implementation of a waste classification system based on concentration. Each waste category (A, B, or C) had limits on nuclide concentrations and requirements for waste packaging and form. One of the deficiencies noted by the DLLWMP in the NRC regulation was the failure to address "Greater than Class C" (GTCC) wastes. While small in volume, there were no provisions in the regulation for management of these wastes. It was the NRC opinion that wastes above the Class C values were generally unsuitable for SLD, and alternative methods of treatment and/or disposal should be used.

In subsequent meetings held among the DOE, NRC, and the DLLWMP, it was agreed that the GTCC wastes required disposal methods which provided "greater confinement" than SLD. One example cited in these discussions was the intermediate depth burial concept proposed by DOE/NV. In 1981, the DLLWMP approved funding for a project at NTS with the specific goal to demonstrate greater confinement disposal technology in an arid region.

## 1.2 Analysis of Waste Streams.

At the start of the project, there was limited guidance as to which wastes were considered unsuitable for SLD. From a regulatory standpoint, the GTCC category of wastes was an obvious choice. However, there were other wastes such as tritium for which SLD had proven to be inadequate containment. Also of concern were thermal energy generating wastes and wastes which required shielding during disposal operations. For purposes of the GCDT, it was decided that greater confinement disposal wastes would not be limited to the category of wastes between LLW and high-level waste but a variety of wastes considered unsuitable for SLD.

Prior to 1978, the majority of wastes disposed at the NTS were from onsite weapons testing programs. These wastes primarily consisted of bulk and packaged debris, primarily soils and rubble. The majority of these wastes were contaminated with low concentrations of beta-gamma and alpha-emitting nuclides. One exception was the small volume of HSA tritium received from Mound Laboratories.

In 1978, as a result of a DOE policy change to discontinue use of commercial disposal sites, the NTS began to receive wastes from several offsite DOE defense waste generators. Initially the NTS began receiving contaminated soils, nitrate salts, and decommissioning debris from the Rocky Flats Plant as well as some additional HSA tritium wastes from Mound Laboratories. As additional generators began shipping to NTS, the trend in volumes and type of wastes being disposed clearly showed that the majority of radioactivity was contained in only a small fraction of the waste volume (see Table 1.1).

As can be seen in Table 1.1, the majority of waste activity (84%) was contained in less that 3% of the total waste volume. Therefore, a logical candidate set of wastes for GCD would be the small volume of HSA-LLW currently being disposed by SLD. By providing

**TABLE 1.1. NTS Low-Level Waste Inventory - Ten-Year Totals(1)**

| Waste Type | Activity (Ci) (%) | Volume ($m^3$) (%) | Concentration (Ci/$m^3$) |
|---|---|---|---|
| Tritium | 4.6E+6 (84) | 5.7E+3 (3) | 8.1E+2 |
| Beta-Gamma | 8.7E+5 (16) | 1.2E+5 (63) | 7.3E+0 |
| Alpha | 5.2E+3 (.1) | 4.7E+4 (25) | 1.1E-1 |
| Stored TRU | 2.5E+2 (.1) | 4.2E+2 (2) | 6.0E-1 |
| U-Th | 1.4E+3 (.1) | 1.3E+4 (7) | 1.0E-1 |
| All Waste | 5.5E+6 | 1.9E+5 | 2.9E+1 |

greater confinement for these wastes, the overall short- and long-term risks associated with LLW disposal would be substantially reduced.

Another candidate waste identified during the preliminary studies was encapsulated isotope sources used in food irradiators and thermoelectric generators. These wastes are highly radioactive and require substantial shielding and precautions in handling. Because of the difficulty in waste handling, the majority of encapsulated sources are being stored, rather than disposed. It was therefore decided that development of a remote waste handling system would be a necessary part of the GCDT and of benefit to the DOE defense waste system.

## 1.3 Design Considerations

The GCDT was developed as an "operational research" project, and it was recognized that balance was necessary between the need to demonstrate a waste disposal technology and the experiments to be conducted to assess the performance of the facility(7,8). In designing the facility and experiments, a series of trade-offs were necessary to accomplish both goals. For example, a minimum of water was used in the drilling and backfilling of holes so as not to introduce additional soil moisture; and vibratory compaction was not used during backfilling operations to reduce the potential damage to downhole instruments. Within each phase of the project, several design decisions were made to accommodate project goals. In hindsight, some alternative designs would have been preferred and will be discussed in later sections.

The principal waste of concern to NTS was HSA tritium. Past experience had shown that tritium migration was due primarily to diffusion through soils covering SLD trenches. Although the tritium was shipped as tritiated water solidified in cement and packaged in bitumen, tritium has the ability to diffuse through waste forms and packaging. Outside the package, the tritium usually becomes either hydrogen gas or water vapor and will diffuse through the porous soils. At the NTS, the low precipitation and high evaporation rates would tend to drive water and light gases to the surface. By placing the tritium wastes at depths greater than the 6-9 meters (20-30 feet) used in SLD, the effective diffusion pathway length is increased and the source is removed from the portion of the soil column where the effects of evapo-transporation are most pronounced. Both of these factors reduce the travel time to the surface. Since depth of burial was the limiting factor in providing confinement, deep augered boreholes provided a reasonable and cost effective alternative to a deep trench for small volumes of waste.

The borehole design was also preferred for handling high radiation sources. Radiation emanating from sources at the bottom of the borehole would be columniated and the sources could be easily covered with backfill material thereby reducing potential exposures to operations personnel.

The initial design for the GCDT was a 46-meter (150-foot) borehole with a 3-meter (10-foot) diameter. However, auger drill rigs available at NTS were only capable of achieving a 36-meter depth (120-foot), and it was decided to proceed with a 36-meter design.

Nine monitoring shafts were drilled around the central borehole and instrumented to detect moisture, temperature, and tritiated soil gas vapors. Since the alluvial soils at NTS are relatively dry, cohesiveness of materials limited the ability of boreholes to remain open, or "free standing." Through a series of test holes, it was determined that a 60-cm (2-foot) diameter was necessary to maintain a free standing hole. Monitoring holes of this size were not desirable because of the large disturbed area around the instruments. The only alternative was to utilize removable casing in each hole and pull the casing after the instrument strings had been lowered into place. This procedure would have been complicated, costly, and potentially damaging to the instrument lines. Therefore, it was decided to proceed with the 60-cm diameter monitoring holes(9).

Another operational consideration was the selection of a remote waste handling system (RWHS) for encapsulated sources. Surveys of potential waste generators had shown that many facilities were storing decommissioned sources in a variety of shielded shipping casks and configurations. The sources were usually configured for a specific cask or device and, in design of these sources, it had been assumed that removal would be performed in a hot cell or storage pool. To accommodate the large variety of sources and casks, the RWHS would need to have a modular structure which could accommodate different configurations of tools used to extract the sources from the casks(10).

# 2.0 GCDT DESIGN AND DEVELOPMENT

Having selected the borehole design and determined the principal transport mechanism, a series of meetings were held to identify suitable locations for the GCDT and design of monitoring equipment. As with most field experiments, availability of electrical power to operate instrumentation and convenience to facilities were principal considerations. Other issues addressed included depth to groundwater, soil chemistry, potential for caliche layers, and ease of drilling.

The original concept for monitoring of the diffusion transport mechanism was based on measuring tritium diffusing from the waste packages. A soil atmosphere sampler system was designed to collect tritiated water vapor and specifications for a temperature and moisture monitoring system were developed.

This Section discusses the characteristics of the GCDT site and the process that occurred in developing, and later changing, the experimental design.

## 2.1 Description of the Site

The GCDT is located in Area 5 of the NTS, near Frenchman Flat (see Figure 2.1) The GCDT is located within the boundaries of the RWMS which serves as

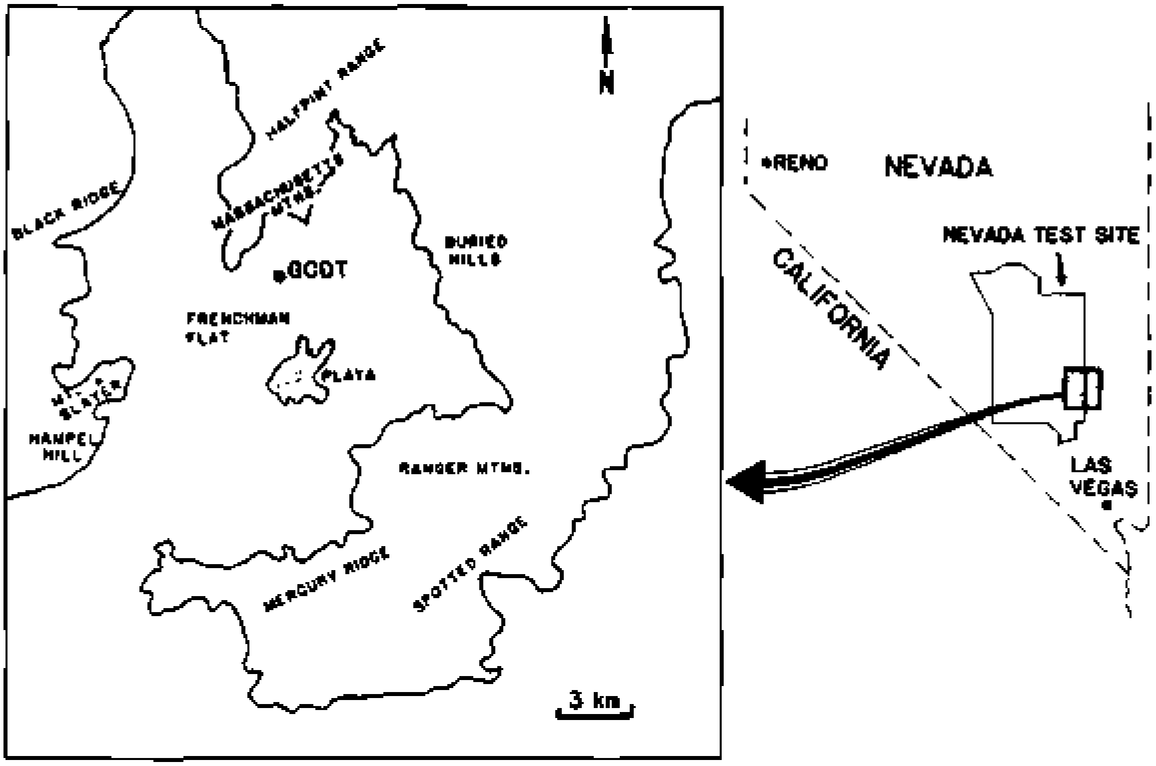


FIGURE 2.1. Location Map for the NTS

the principal location for disposal of offsite-generated defense LLW.

**2.1.1 Geologic Setting.** The GCDT is located on an alluvial fan in the Frenchman Flat area of the NTS. The site is characteristic of the southwest's Basin and Range geology(11). The area is bordered to the northwest by the Massachusetts Mountains, by Mt. Slayer and Black Ridge to the west, by the Buried Hills to the east, and by Mercury Ridge to the south (see Figure 2.1). Frenchman Flat is a closed basin primarily composed of quaternary alluvium, although at its center is a large playa deposit of silt and clay (see Figure 2.2). The Massachusetts Mountains are Tertiary volcanic tuffs and ash flows. The mountain perimeter to the east is Paleozoic, mostly undifferentiated carbonate and quartzite formations. Mercury Ridge is a mixture of Tertiary and Paleozoic material. A gravity survey of Frenchman Flat indicates that the greatest depth, in excess of 460 meters, to the basement Paleozoic carbonates is approximately 2 Km. southeast of the GCDT(11). Directly beneath the GCDT site the depth to bedrock is approximately 400 meters (see Figure 2.3).

**2.1.2 Soils.** The soil at the GCDT developed in a high temperature, low rainfall environment. Based on particle size distribution, the soil may be classified as a sandy loam. It is coarse-textured with a low organic content(12). Soil moisture ranges between 10 and 12 percent of the matrix pore volumes. With the very low moisture content, the unsaturated hydraulic conductivity of these soils is approximately $10^{-10}$ cm/s(13). The alluvial material collected during drilling of the emplacement and monitoring holes showed the soil to be relatively homogeneous. A few lenses of coarser material were the only notable exceptions. Although an accumulation of carbonate salt within a few meters of the surface commonly results in a caliche layer in NTS soils, caliche was not identified during drilling(14).

The limited availability of water minimizes rates of soil formation and produces coarse-textured, weakly-structured soils with low clay and organic matter content. The alluvium at the site has a clay content of about 5-15 percent. X-ray analyses of the clay fraction indicate that its composition is mostly montmorillonite, illite, and the zeolite mineral, clinoptilolite. Quartz, feldspar, and calcite are also present in the fine silt and clay fractions(13).

Sorption properties of site soils were studied by applying spiked solutions of varying cesium and strontium concentration strengths to soil samples(12). Data indicate that sorption of cesium$^+$ is much more efficient than sorption of strontium$^{2+}$. The soil sorbs celsium + preferentially over strontium$^{2+}$ indicating that the lyotropic series for the soil is different than for pure montmorillonite. The sorption affinity of the illite and clinoptilolite for cesium$^+$ apparently overwhelms the affinity that montmorillonite has for sorbing strontium$^{2+}$.

The average maximum sorption of cesium$^+$ is 21 mg per gram of soil, and for the strontium$^{2+}$ is 3.5 mg per gram of soil. Assuming an average bulk density of 1600 kilogram/cubic meter for the GCDT site soils, the average maximum sorption per unit volume of soil would be 33.60 kilogram/cubic meter for cesium$^+$ and 5.34 kilogram/meter for strontium$^{2+}$. The maximum sorption of these ions on an equivalent basis per unit volume would be 252.8 equivalents per cubic meter for cesium$^+$, and 122.0 equivalents per cubic meter for strontium$^{2+}$. Results of these studies indicate that the ion sorption properties of NTS soils would be adequate to effectively retard large quantities of cesium and strontium under normal and abnormal environmental conditions.

**2.1.3 Groundwater.** The groundwater system below the GCDT is part of the Ash Meadows aquifer. This regional aquifer is an interbasin flow system in the basement Paleozoic carbonates which is relatively independent of the topographic boundaries of Frenchman Flat (Figure 2.2)(11). Below the GCDT, the Ash Meadows aquifer occupies the lower portion of the Cenozoic alluvial fill. Figure 2.3 illustrates the direction of groundwater flow under the GCDT, generally south to southwest. Depth to water at the study site is 245 meters, increasing toward the mountain perimeter(11).

The shortest contaminant release pathway at the GCDT is upward through the 20 meters of backfill soil to the ground surface. Downward unsaturated flow must traverse over 200 meters of dry alluvium to reach the unconfined regional aquifer. Given the very small conductivities for soil, the estimated travel time through the unsaturated media is estimated to be over

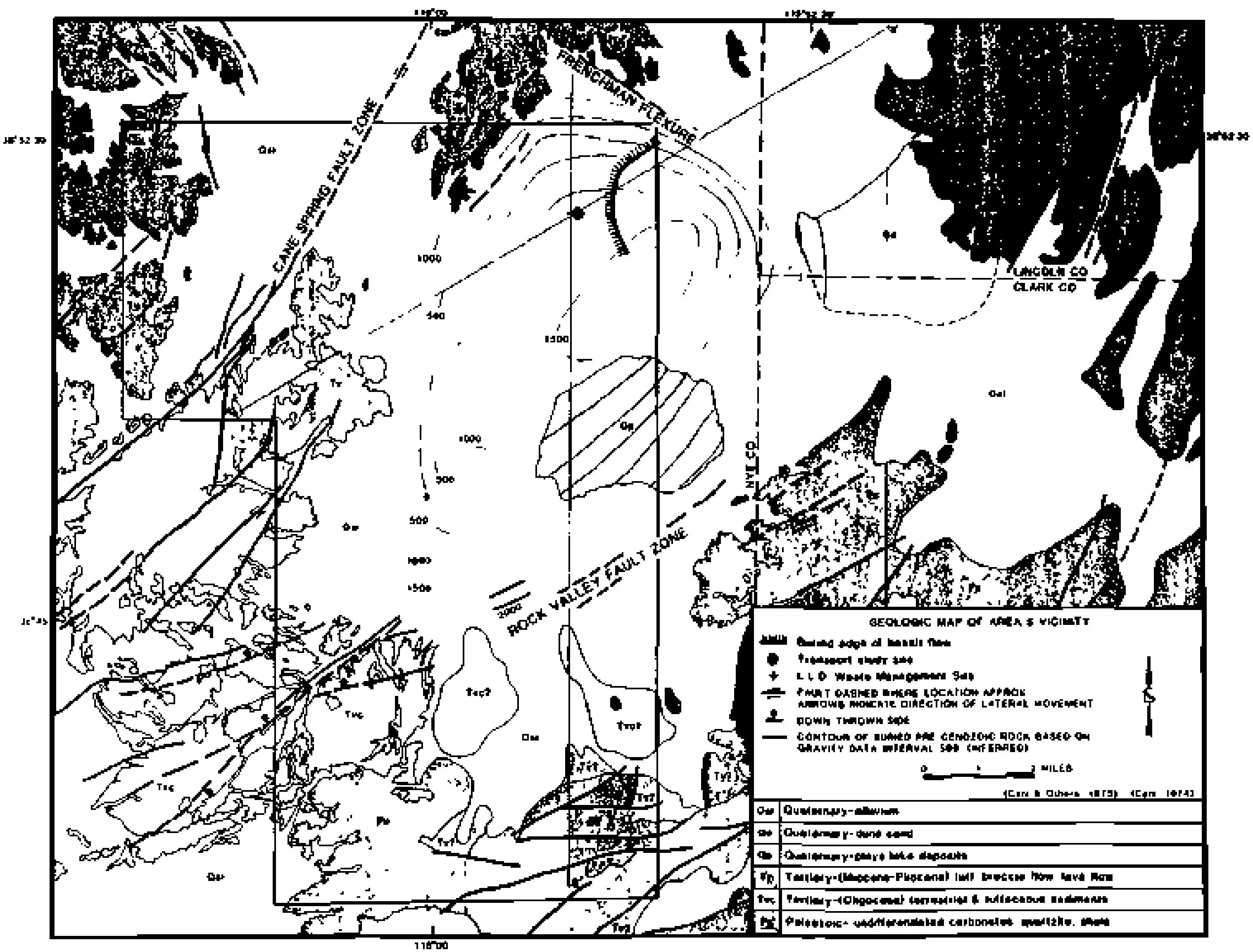


FIGURE 2.2. Geologic Map of Area 5 and Vicinity

100,000 years[15]. Also, transit time to the discharge point at Ash Meadows is conservatively estimated in excess of 3000 years once the contaminants enter the regional saturated flow system[16]. Since the majority of disposed radioactive wastes would decay to one percent or less of original curie content within 200 years, their discharge at Ash Meadows is not a pathway of concern[11].

## 2.2 Facility and Instrument Designs

The GCDT consists of a central emplacement shaft and 9 monitoring shafts (Figure 2.5). The emplacement shaft is 36 meters deep and 3 meters in diameter. The monitoring shafts are the same depth, but only 60 centimeters in diameter. Monitoring shafts are orbitally staggered at radii of 3, 4.9, and 6.7 meters. They are identified by radial distance from the emplacement shaft center and by azimuth, such that 640-120 describes the southeastern (120°) monitoring shaft furthest (640 cm) from the center of the emplacement

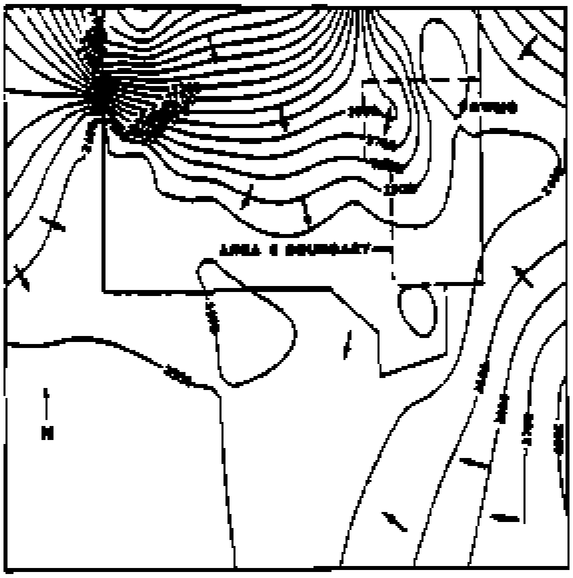


FIGURE 2.4. Water Table Map of GCDT Area

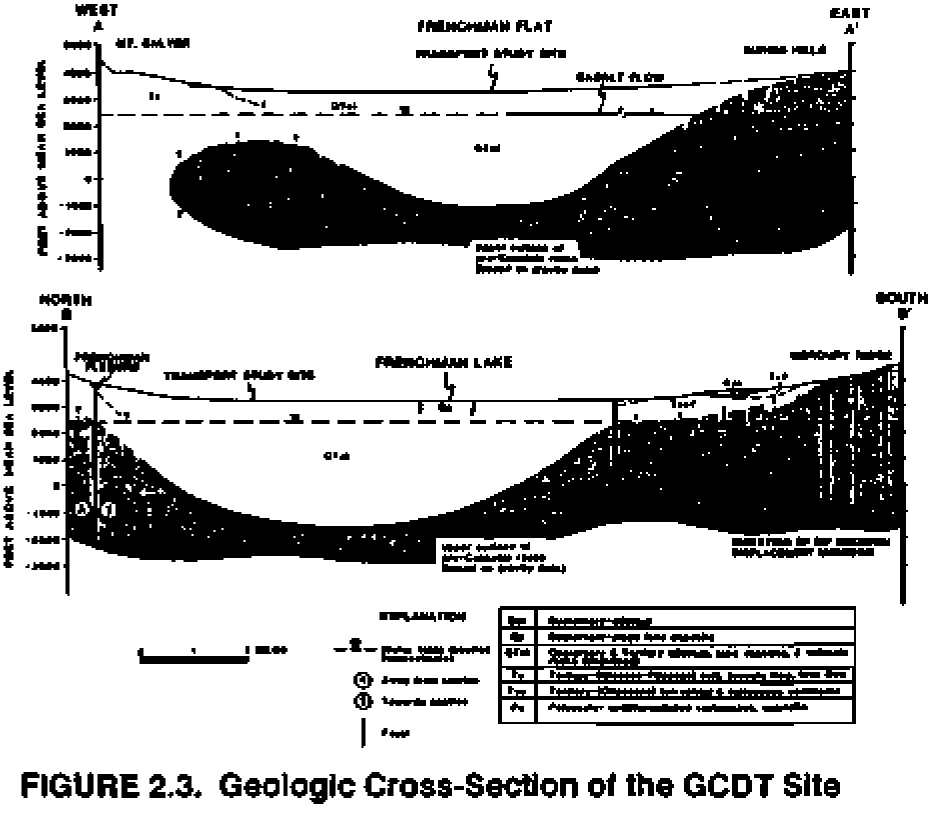


FIGURE 2.3. Geologic Cross-Section of the GCDT Site

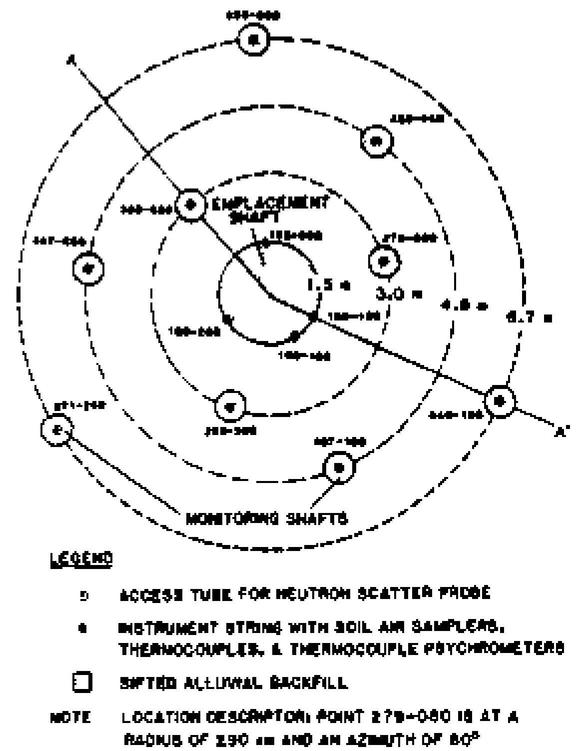


FIGURE 2.5. Planar View of the GCDT

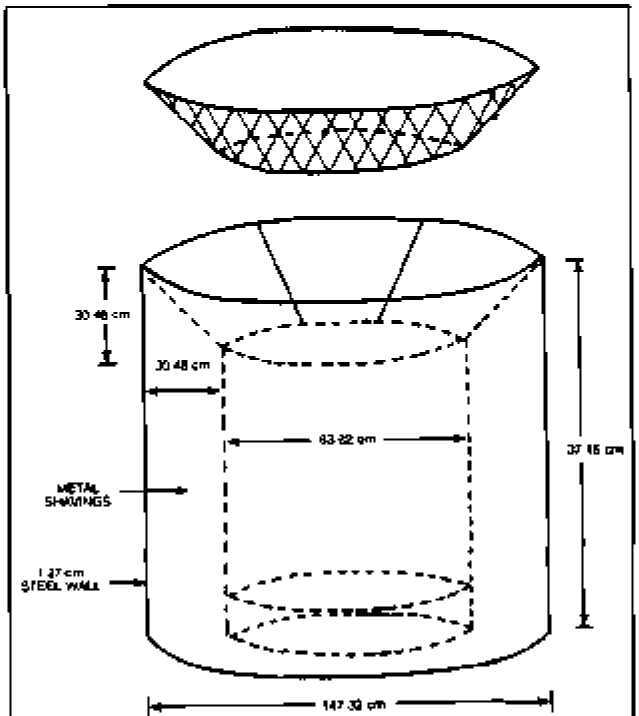


FIGURE 2.7. Detail of the GCDT Thermal Dissipation Source Drum

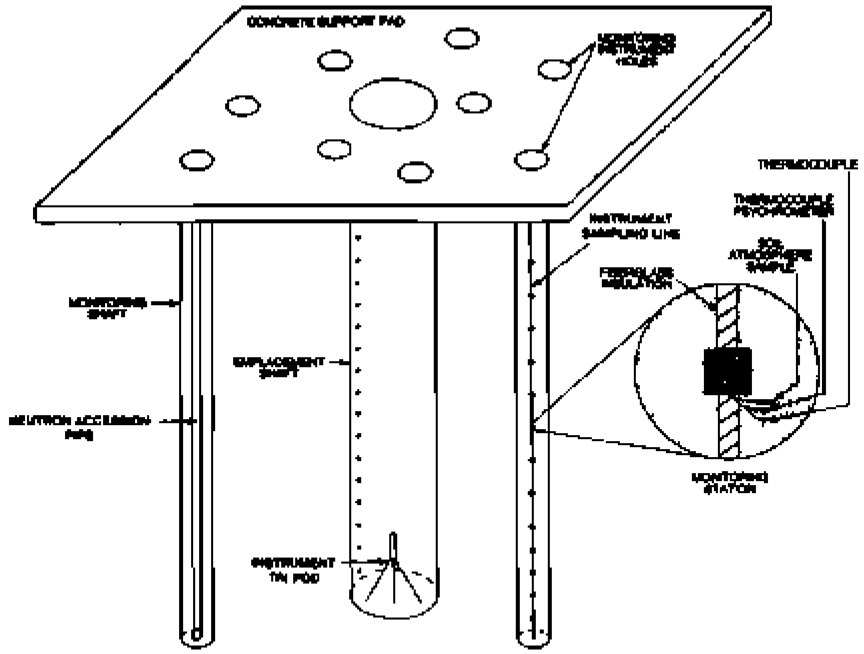


FIGURE 2.6. Cross-Sectional View of the GCDT

shaft. All holes were backfilled with fine-graded, sifted alluvium.

The GCDT had 9 instrument lines with a total of 144 monitoring stations. Each contained a soil-atmosphere sampler, thermocouple psychrometer, and an independent thermocouple. Three instrument lines were positioned along the perimeter of the emplacement shaft; the other 6 are in monitoring shafts. The bottom 8 stations of the emplacement shaft instrument lines had 2 thermocouples and psychrometers each. Three monitoring shafts were reserved as access ports for a neutron scatter probe.

Figure 2.6 is a cross-sectional scale view (through transect A-A' in Figure 2.5) illustrating the instrumentation of the GCDT. Monitoring stations for each line were spaced every 3 meters down to a depth of 24.4 meters, and every 1.5 meters thereafter, totalling 16 sample stations per instrument line. Shaft 305-320 contained an aluminum neutron probe access tube for soil moisture measurements at any depth. The central emplacement shaft had a 5.5-meter-tall tripod at the bottom, used to position the 3 central instrument lines along the shaft perimeter. Four monitoring stations were included on the tripod as an extension of line 160-250.

Upon completion of drilling, the instrument lines and the neutron and gamma access tubes were emplaced and the monitoring shafts were completely backfilled with sifted alluvium. The emplacement shaft was backfilled to the 30.5-meter depth to cover the tripod anchor and to provide a flat surface for the placement of a thermal dissipation source drum detailed in Figure 2.7. The source drum is 147 centimeters in diameter, 137 centimeters tall, and has a 30-centimeter-thick hollow wall filled with metal shavings. The purpose of the drum was to hold the heat-generating encapsulated sources and distribute the thermal energy over a larger surface area and prevent excessive heating of the soils in direct contact with the sources.

## 2.3 Analytical and Monitoring Systems

The most significant design change made in the development of GCDT occurred shortly after the monitoring lines were installed. Early in the project, diffusion was identified as the only major transport mechanism. This led investigators to design a soil atmosphere sampling system similar to ones used in other tritium monitoring experiments at NTS. The system would utilize low volume air pumps to draw soil gases across a cold trap to condense tritiated water vapors. By analyzing the amount of tritium contained in the soil gas and moisture, the diffusion rates could be determined.

The two major drawbacks to this system were that the tritium source term (ie. the rate of tritium diffusion from the buried waste packages into the surrounding soils) would be uncertain, and secondly, the continual removal of soil atmosphere at deep sampling locations could induce convective flow. After several technical reviews and discussions of alternative concepts, it was decided to proceed with the basic design. This design included the use of 1/4-inch diameter teflon tubing for the principal sampling line. Plastic tubing was selected over metal primarily because of weight consideration and concerns over possible crimping of lines during installation.

In 1983, the work being performed by Kreamer and Thompson[17,18,19] in fluorocarbon soil gas tracers became known to the GCDT investigators. These tracers had diffusion rates significantly greater than tritiated water vapors and could potentially provide the data necessary to characterize the diffusion properties of the GCDT soils because a known source term could be introduced.

The advantages to utilizing fluorocarbon tracers over the tritium sampling system were considered significant and a decision was made to modify the experimental design. The major obstacle to implementing the system used by Kreamer and Thompson was in the teflon tubing.

**2.3.1 Tracer Data Analytical System.** The Tracer Data Analytical System (TDAS) was developed to address sampling problems associated with the original GCDT soil gas sampling design. The amount of soil gas sample required to analyze for fluorocarbon tracers was only a few milliliters. The annulus air volumes of the 1/4-inch diameter teflon tubing would significantly dilute the sample and introduce substantial sample error. Therefore an alternative sampling system would need to be developed.

The TDAS system evolved from a series of discussions centered on the need to minimize convective flow and find a means of obtaining a valid sample from each

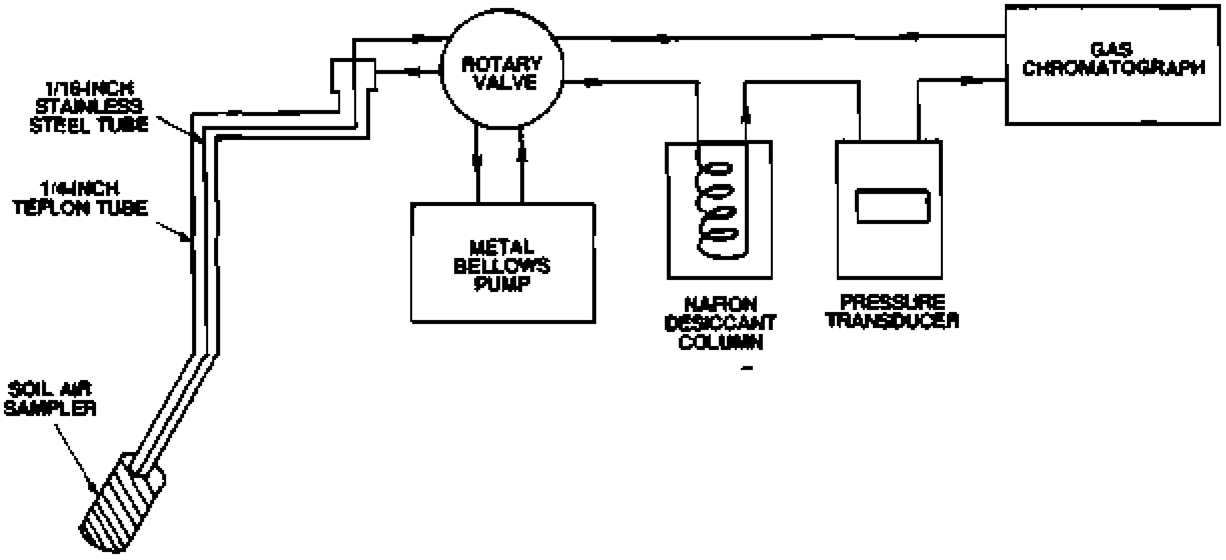


FIGURE 2.8. Schematic of the Tracer Diffusion Analytical System

sampling location. With only a few milliliters of air being drawn at a time from each sampling location, it would take several hours to analyze the annulas air volumes. [It should be noted that at the time, column gas chromatography (GC) was the principal method used for detecting fluorocarbons. Detection systems which could have been used "in-line" to constantly analyze the air being drawn from the tubing were not yet available.] Since it was expected that the tracers would diffuse rapidly, each station would need to be sampled several times a week to assure tracer breakthrough points were obtained. Both the time required to perform this sampling and the concerns over withdrawal of subsurface air volumes led to the development of a recirculating sampling system.

The basic design of the TDAS is shown in Figure 2.8. A 1/16-inch outside diameter stainless steel tube was inserted into each of the teflon tubes. A T-junction was attached to the top of each teflon tube and 1/16-inch stainless steel tubing was used to run a sample loop to a rotary valve. Connected in line to the valve were a metal bellows pump, pressure transducer, and gas chromatograph. At the start of each sampling, the valve was rotated to allow the pump to draw air from the tubing and return it, creating a closed system. The metal bellows pump provides a constant flow rate and by timing the pump, a fairly accurate measure of flow volumes can be determined. The annulus air volumes for both the teflon and stainless steel tubes were calculated and flow rates intervals determined. After the appropriate pumping interval, the valve was rotated to the gas sampling loop. The samples were drawn through a nafion dessicant system to remove water vapor and into the GC. The GC contained a chromatographic column and an electron capture detector[11,16]. Figure 2.9 shows the TDAS pump and valve arrangement used for GCDT. Figure 2.10 shows the TDAS control panel.

While the TDAS system solved many of the problems identified with both the original tritium sampling system and use of fluorocarbon tracers, it was an untried design and required a substantial amount of effort to obtain satisfactory results.

**2.3.2 Remote Data Acquisition System.** The Remote Data Aquisition System (RDAS) was originally conceived as a mean of automating data collecting from the thermocouples and TCPs. With a total of over 300 TCPs and thermocouples, the time required to obtain readings would be substantial. Also, it was known that the TCPs were complex and sensitive instruments and TCP reader/recorders were difficult to use. Therefore, it was decided to try to develop a prototype data

FIGURE 2.9. TDAS Pump and Valve Arrangement

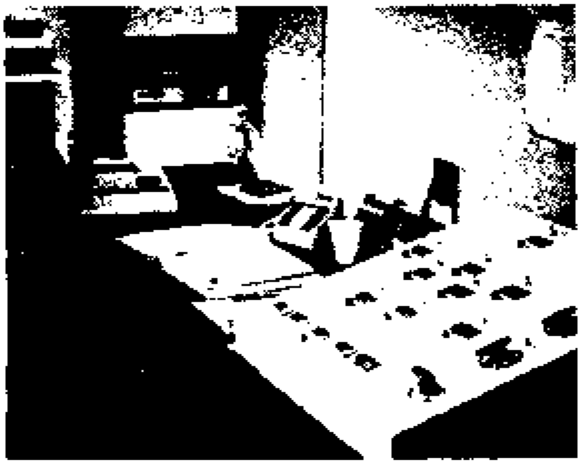


FIGURE 2.10. TDAS Control Panel

acquisition system that would automate the reading of these devices.

The RDAS system was designed by EG&G Special Projects Division and involved a combination of specially-designed electronic circuit boards and computer software program. In the laboratory, RDAS functioned as intended. However, in the field, the RDAS provided erratic and inconsistent data and was discontinued in favor of manual recordings.

Why the RDAS did not function in the field was never completely determined and will be discussed later.

# 3.0 WASTE HANDLING SYSTEM AND OPERATIONS

The handling of waste packages exceeding 200 mrem at contact is cause for special concern[20]. Equipment operators and waste handling personnel must monitor radiation levels and time of exposure. The operating philosophy of keeping exposures as low as reasonably achievable is fundamental to all NTS activities. Given the very high radiation levels of many HSA wastes, it was necessary to develop a remote system for handling of waste packages and procedure for limiting exposures to personnel.

## 3.1 Remote Waste Handling System

As discussed earlier, one waste stream identified as requiring GCD was highly radioactive sealed sources. These sources must be transported in shielded casks and remotely handled. While many DOE LLW disposal sites do provide for remote handling of large canisters, none were equipped to handle small sources or a variety of source types.

In developing the Remote Waste Handling System (RWHS) for the GCDT, the following design features were considered necessary[10]:

- All-weather construction for use in field operations.
- Full remote operation up to a distance of 150 meters.
- Ability to handle a variety of waste sources and packages.
- Ability to handle 227-kilograms loads for placement at depths up to 36 meters.
- Ability to visually monitor above and below ground operations through a remote-controlled video system.
- Usable in other routine waste management operations.

Based on these criteria, a modular RWHS consisting of 3 principal elements was developed. The first was an 18-ton, all-terrain crane that was modified to allow remote control of the boom and reeling functions (Figure 3.1). During remote operations, the crane body is kept stationary. The boom controls (i.e., telescope, swing, hoist, and angle) are electro-mechanical and give the operator inching capability. To facilitate placing sources downhole, the boom angle and swing controls can be set so that remote indicators light up when the end of the boom is centered over the GCDT shaft. A camera, located behind the crane cab, monitors a set of crane function indicators, which include fuel level, oil pressure, engine temperature, and boom angle. The crane can be operated manually for routine operations.

The second part of the RWHS is the remote-controlled grapple module (Figure 3.2). The module is suspended from the crane hoist hook and has a separate set of control systems. The module provides a 360-degree rotational capability, positive pressure locking pin and clevis grapple, and remotely controlled video camera and light. The module also contains a load cell transducer to provide readouts on weight of lifting loads. The module was designed to allow rapid change-out of a variety of lifting tools.

Automatic cable uptake reels for the camera, lighting, and power cables are mounted on the crane boom. In addition to the grapple camera, the aboveground surveillance camera that can be positioned for remote viewing of the entire waste handling operation is included. Both cameras have pan, tilt, and zoom capabilities. When used in tandem, the cameras provide the operators with some degree of depth perception[10].

The camera on the grapple module allows close-up viewing of source pickup operations. This permits the crane operator to properly and efficiently position the grapple module while using the remote controls. This camera also allows viewing of downhole operations. With this capability, the waste can be positioned in the

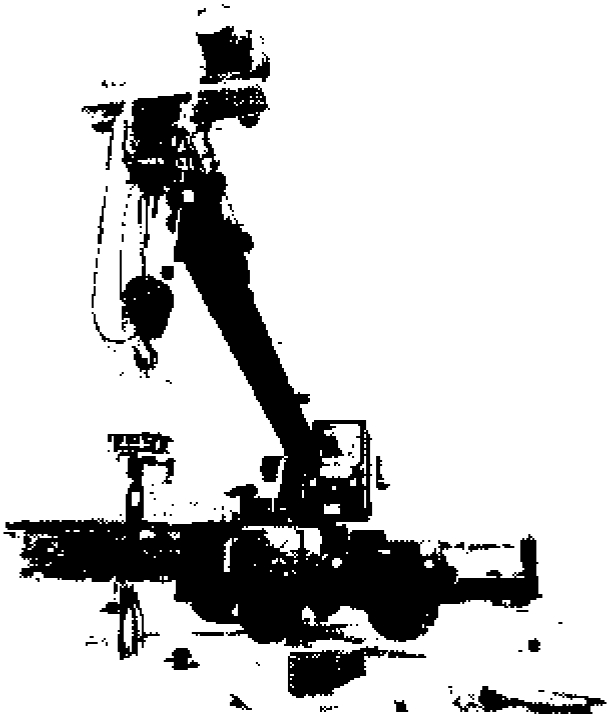


FIGURE 3.1. GCDT Remote Control Crane and Grapple Module

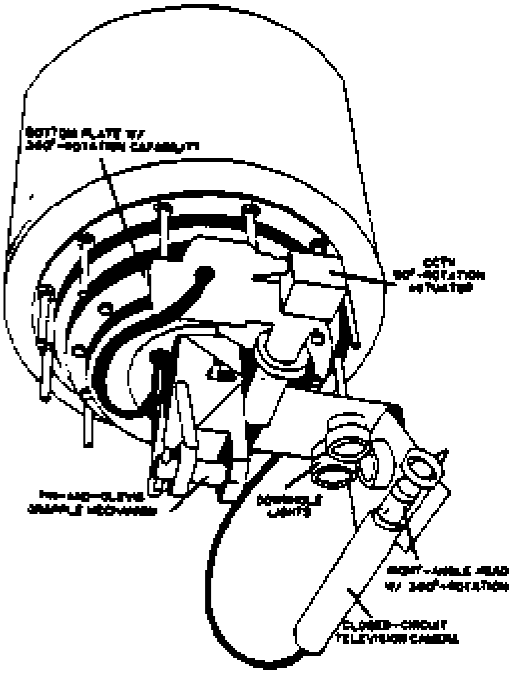


FIGURE 3.2. GCDT Remote Controlled Grapple Module

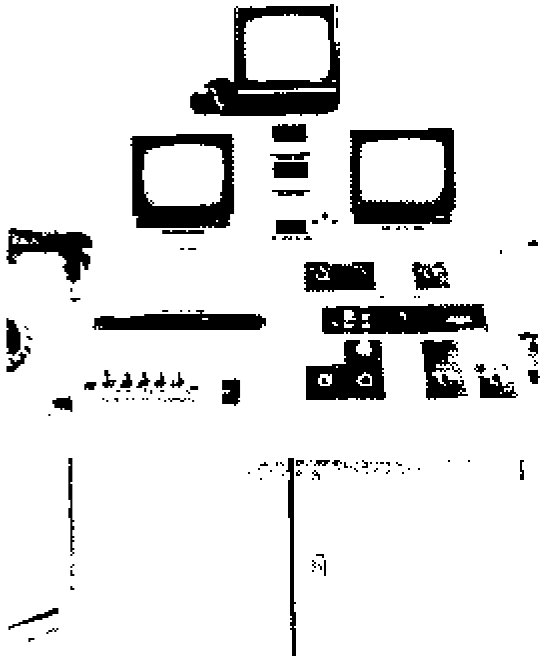


FIGURE 3.3. RWHS Remote Control Console

disposal shaft to attain higher loading efficiencies than would otherwise be possible.

The third part of the RWHS is the remote console for controlling the operation of the crane, grapple module, and video components (Figure 3.3). The console was designed to be mobile and capable of withstanding the climatic conditions at the NTS.

## 3.2 Waste Emplacement Operations

Prior to conduct of remote waste loading operations, detailed operating procedures and contingency plans were developed. Time, distance, and shielding calculations were performed to assure that personnel exposures would be as low as reasonably achievable.

An 8-meter high soil dike was constructed adjacent to the GCDT pad to provide shielding for operations personnel located approximately 120 meters behind the dike. While the shielding dike eliminated all direct radiation, skyshine and scatter radiation were detectable[1,20,21].

The HSA encapsulated sources were free-air transferred from their transport casks downhole to the source drum using the RWHS. Concentrated and environmentally mobile tritium waste packages were emplaced in several stages, such that levels may be identified in the shaft. Levels are differentiated by source material or by backfill interval. To minimize void spaces during backfilling, sifted alluvium was poured downhole at appropriate intervals as dictated by the form or quantity of deposited waste. Dimensions and source level depths are illustrated in Figure 3.4 and disposal volumes and materials are presented in Table 3.1.

Several strontium-90 , cesium-137, and cobalt-60 encapsulated sources were placed in the source drum. Backfill material in Level B was poured into the emplacement shaft, resulting in coning of subsequent source layers. Level C contains strontium-90 in thermoelectric generators, and radium-226 and actinium-227 in 210-liter and 114-liter drums, respectively. Levels D through F contain tritium in 210-liter drums. Levels A and G only contain sifted alluvium. The shallowest source is tritium, in Level F, 19.5 meters below ground surface.

Total activity of the disposed waste was 1.11 megacuries as of May 1, 1984. The encapsulated source total was approximately 517 kilocuries, 96 percent of which is attributable to strontium-90. Total

**TABLE 3.1. GCDT Disposed Wastes**

| Level | Layer Depth (m) | Material | Activity (kilocuries) | Thermal Output (Watts) |
|---|---|---|---|---|
| G | 20.7 | Alluvial Backfill | -- | -- |
| F | 23.2 | Tritium - 35 Drums | 175.3 | 5.9 |
| E | 25.6 | Tritium - 28 Drums | 266.2 | 9.0 |
| D | 27.7 | Tritium - 13 Drums | 152.1 | 5.1 |
| C | 29.6 | Sr-90<br>Ra-226<br>Ac-227 | 40.0<br>0.1<br>0.01 | 273.2 |
| B | 30.5 | Sr-90<br>Cs-137<br>Co-60 | 456.0<br>20.5<br>0.4 | 3164.9 |
| A | 36.0 | Alluvial Backfill | -- | -- |

tritium activity amounted to approximately 593.6 kilocuries(14,16).

## 3.3 Radiological Considerations.

To assess the effectiveness of the radiological protection afforded by the RWHS and GCDT facility design, a series of experiments were conducted during the remote transfers of HSA waste capsules. An array of thermoluminescent dosimeters (TLDs) and real-time radiation detectors were placed around the GCDT pad and locations both in the line-of-sight from the sources and as behind the shielding dike. Results of these studies have been published(1,21,22), and are summarized as follows:

a. The radiological protection afforded by the use of systems for GCDT was excellent. There were no recordable exposures to personnel during any of the remote operation.

b. Data collected from the experiments were used to validate the SKYSHIN computer code. This code was specifically developed for calculating radiation doses over barriers.

c. Inadequate documentation on the encapsulated sources resulted in the underestimation of radiation levels. In particular, the contributions of bremsstralung radiation from strontium sources were greater than expected.

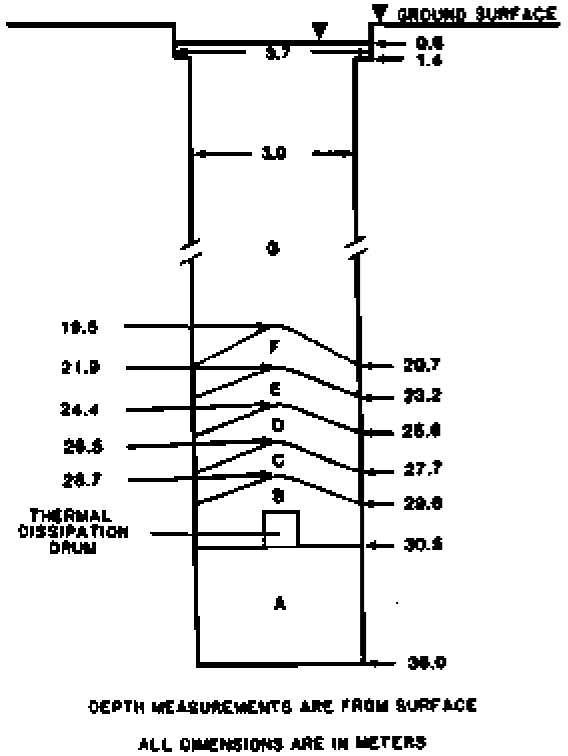


FIGURE 3.4. GCDT Shaft and Stemming Levels

# 4.0 MONITORING AND TRACER EXPERIMENTS

The arid climate of the NTS and the thick alluvial soils underlying the GCDT provide for an excellent LLW disposal site. However, these same conditions limit the ability to effectively monitor and model the site. With diffusion as the only major transport mechanism, migration of materials from the disposed wastes is very slow. While the slow migration process is ideal for disposal conditions, it also requires extended periods of monitoring to detect changes.

GCDT monitoring systems were primarily designed to measure changes in temperature and soil moisture content due to the thermal generating wastes. Tracer tests were developed to simulate gaseous waste (*i.e.* tritium) migration and measure the diffusive properties of the GCDT soils.

This Section presents the experiments conducted in the GCDT project and discusses some conclusions about the experiment and data collected.

## 4.1 GCDT Temperature and Moisture

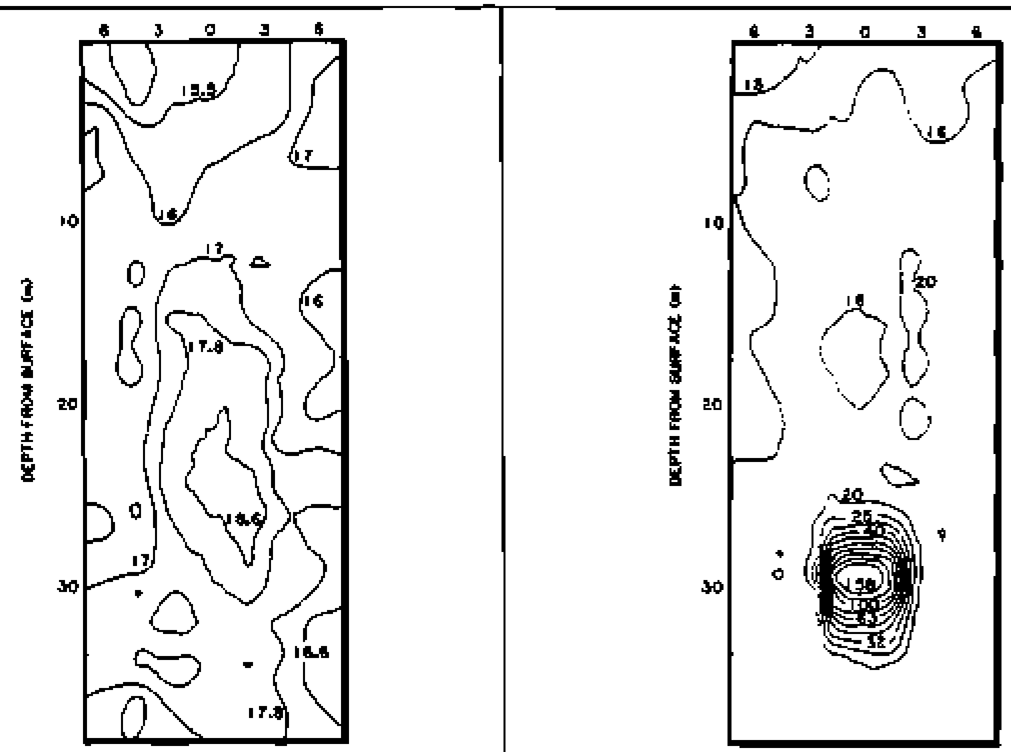
Soil temperature and moisture data were collected at several points within the disposal borehole and monitoring shafts. These data were collected to analyze the effects of thermal generating wastes on surrounding soils and the fate of soil moisture. The principal devices used in monitoring temperature were the Type J thermocouples. The thermocouple portions of the TCPs were also used but were limited to 50°C.

Baseline measurements for temperature were made during the latter part of 1982 and the beginning of 1983 (see Figure 4.1 (a)). The average ambient subsurface temperature was approximately 17°C. Waste loading operations were completed in March of 1984 and the shaft was backfilled. Changes in temperature were first observed at a radius of 2.8 meters after 30 days, 4.5 meters after 90 days, and 6.3 meters after 120 days[14]. During the first 30 days after closure, temperature exceeded 100°C within 1.6 meters of the thermal sources (See Figure 4.1(b)). The temperature within the waste emplacement zone exceeded 300°C within 100 days after closure. Figure 4.1(c) shows the temperature profiles approximately two years after closure. Vertical heating of the shaft backfill material clearly exceeds that in the horizontal direction. This distribution is due to both the tendency for upward convection of heat as well as the lower density of the backfill compared to surrounding soils. Figure 4.1(d) presents temperature profiles for June 1988, approximately 50 months after closure[23]. Results indicate that temperature in the proximity of the disposal zone has reached equilibrium.

Soil moisture measurements were obtained using a neutron scatter soil moisture probe and thermocouple psychrometer. Due to numerous problems in the reading of TCPs, they provided little useful data[24]. The most reliable results were obtained from the 4 neutron access holes. Measurements made in February 1984 showed initial soil moisture to be approximately 10 to 12% by volume (See Figure 4.2 (a)).

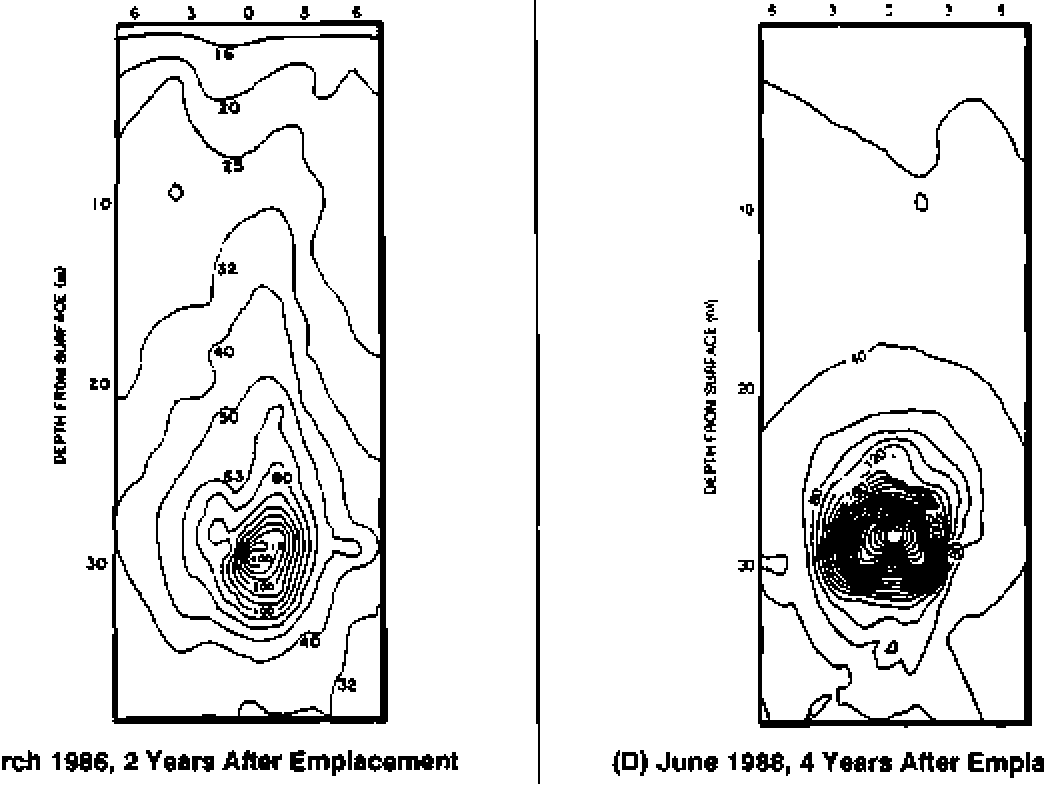
During July and August of 1984, localized thunderstorms caused ponding of water on the concrete GCDT pad and run-off water infiltrated the emplacement and monitoring shafts. The moisture levels increased to approximately 26% in near surface soils and a wetting front extended downwards to approximately 4 meters[14]. After the occurrence of these rainstorm, precautions were taken to seal the shaft covers to prevent the further introduction of run-off water. The concrete pad served as a moisture barrier, preventing the evaporation and drying of the soils. Consequently, the soil moisture volumes under the GCDT pad remained higher than background for two years after the 1984 thunderstorms (See Figure 4.2(b)). The topographic presentations of soil moisture in Figure 4.2 show the effects of heating in the disposal zones. As soil temperatures increased, water vapor diffused outward from the heat sources, creating localized zones of higher moisture.

While the usual processes for redistribution of soil moisture are matric potential and vapor transport, it is believed that gravity drainage may also be an influencing factor[24]. Gravity drainage will occur when the



(A) February 1983, 1 Year Before Emplacement

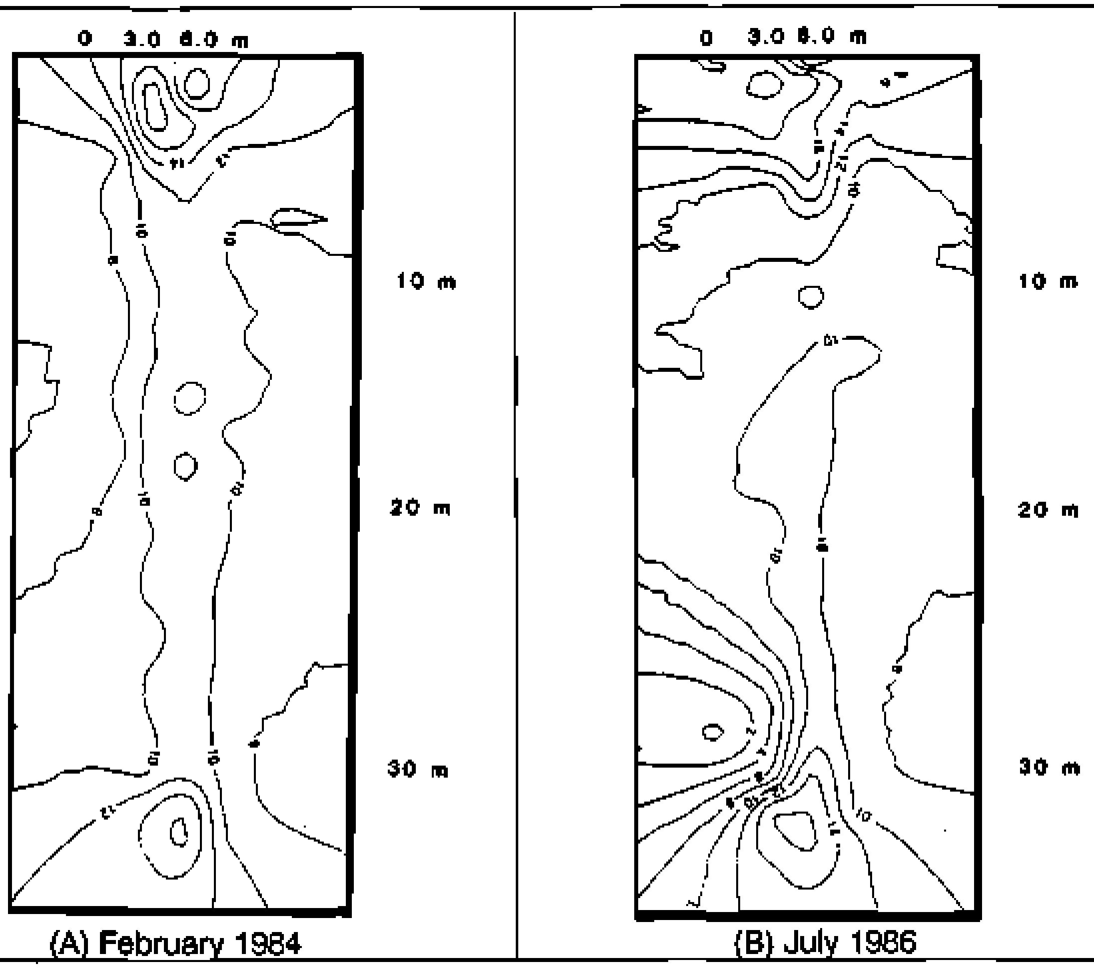
(B) March 1984, 1 Month After Emplacement



(C) March 1986, 2 Years After Emplacement

(D) June 1988, 4 Years After Emplacement

FIGURE 4.1. GCDT Soil Temperature Profiles (°C)



(A) February 1984 (B) July 1986

FIGURE 4.2. GCDT Soil Moisture Profiles

volume of soil moisture approaches saturation levels. While the evidence for this is not yet apparent in GCDT data, it was predicted in early modeling studies conducted by LANL.

## 4.2 Preliminary Tracer Studies

As discussed earlier, the TDAS was a modification to the original experimental design for GCDT. A recirculating tracer sampling system of this type had not been used before and a significant amount of time was spent in modifying and adjusting the system to obtain reliable results. For more than 18 months prior to the start of tracer testing in GCDT, a series of preliminary tracer tests were conducted. The first two tests to be conducted using TDAS were performed in the Shallow Test Plot (STP). Results from these test were unsatisfactory and there were several questions concerning the operation of the system and the effect of dilution caused by drawing and recirculating the annulus air volumes within the teflon tubing. There were also questions as to the effects of pump-induced convective flow which would essentially eliminate the purpose of the recirculating sampling system.

**4.2.1 Recirculation System Test Container.** To address the questions raised during the first STP tests, a Recirculation System Test Container (RSTC) was developed.

A series of six diffusion tests were conducted using the RSTC. The primary purpose of the tests were to assess individual component and system configurations in a controlled laboratory situation[25]. The RSTC consisted of a 90- x 60- x 60- centimeters box filled with

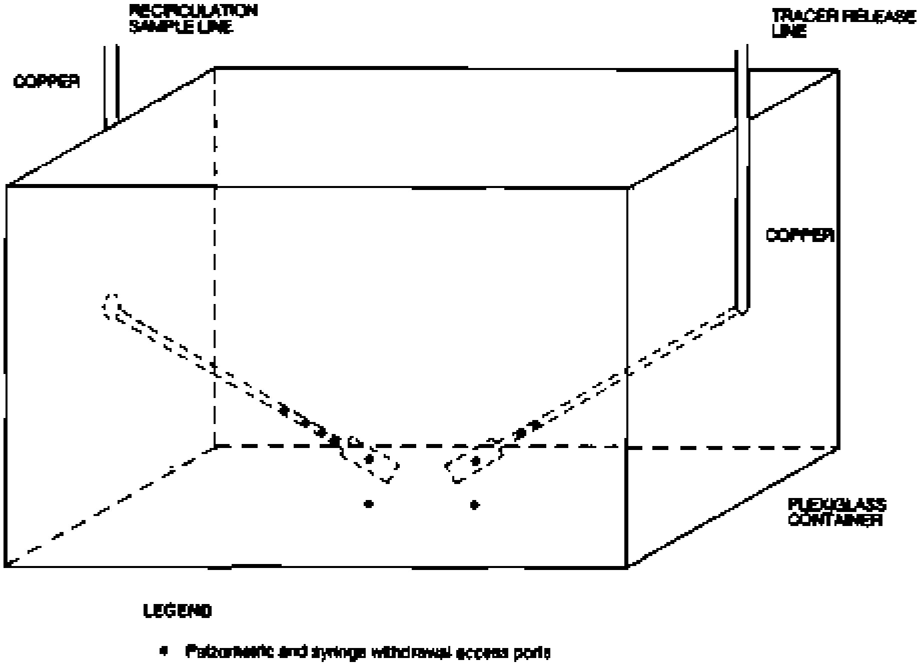


FIGURE 4.3. RSTC Illustration

alluvial soils (See Figure 4.3). Horizontal penetrations were made through the box at various radial distances around the injection and sample points. Ports were created to allow both the direct injection and withdrawal of soil gas samples using a syringe.

The first test (RSTC-1) was to collect data on the pressure distribution within the sampling system and to determine if convective flow was occurring. RSTC-2 and RSTC-3 were "slug" tests involving the direct injection of 10 milliliters of a 1 ppm bromochlorodifluoromethane (BCF) standard gas into the soil air sampler and outside the sampling head. In both tests, air was drawn from the teflon tubing and reinjected through the 1/16-inch stainless steel tubing. Results showed an unsatisfactory recovery of sample and excessive dilution of the tracer. These tests confirmed that in order to utilize the recirculation sampling system, samples would need to be drawn from the 1/16-inch tubing[25].

RSTC-4 and RSTC-5 were similar to tests 2 and 3 except the sampling lines were reversed, and samples were drawn from the 1/16-inch tubing. Also to prevent cross-contamination from the previous tracer, a 1 ppm sulfur hexafluoride ($SF_6$) standard gas was used. Results of these tests showed a more consistent and interpretable set of results. These tests also showed no apparent clogging of lines that could have been caused by drawing fine soil particles into the 1/16-inch tubing[25].

The last test, RSTC-6, used Freon-12 and Freon-13B1 tracers. Syringe samples were drawn from the soil around the sampling and injection point to determine tracer source release characteristics.

The results of the RSTC tests were:

a. No apparent convective flow was induced by the recirculation system.

b. Air samples needed to be drawn from the 1/16-inch tubing in order to obtain reproducible results. Also, clogging of sample lines did not occur.

c. Critical to obtaining reproducible results was the careful monitoring of pump times and line pressures.

**4.2.2 Shallow Test Plot.** The STP was a small scale version of the GCDT and was used to test both tracer sampling and as temperature and soil moisture systems. The STP was a 3-meter-diameter shaft augured to a depth of 6 meters (See Figure 4.4). Instrument

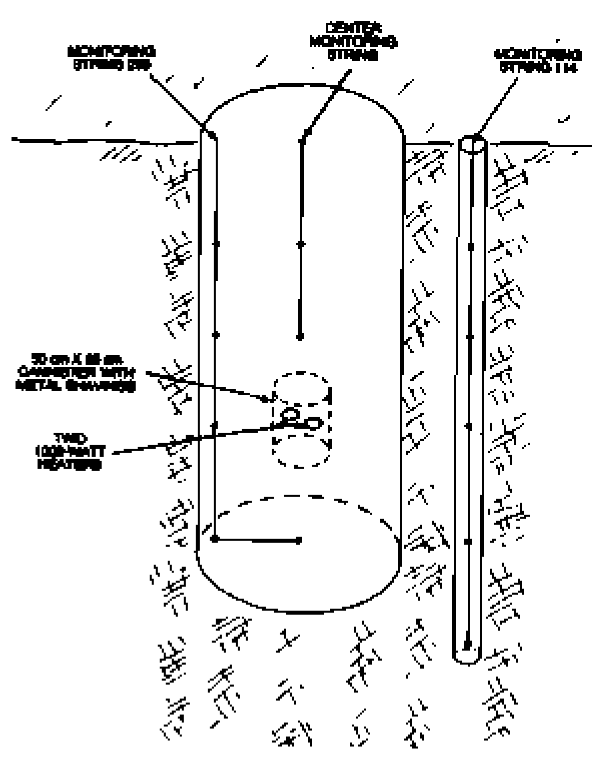


**FIGURE 4.4. Shallow Test Plot Configuration**

strings and neutron soil moisture probes were emplaced in the shaft. A 55-gallon drum filled with metal turnings and containing two 1000-watt electrical resistance heating elements was placed in the center of the shaft at a depth of approximately 4 meters. The instrument strings, sampling lines, and backfill materials were the same as those used for GCDT. The 55-gallon drum was used to simulate thermal generating waste.

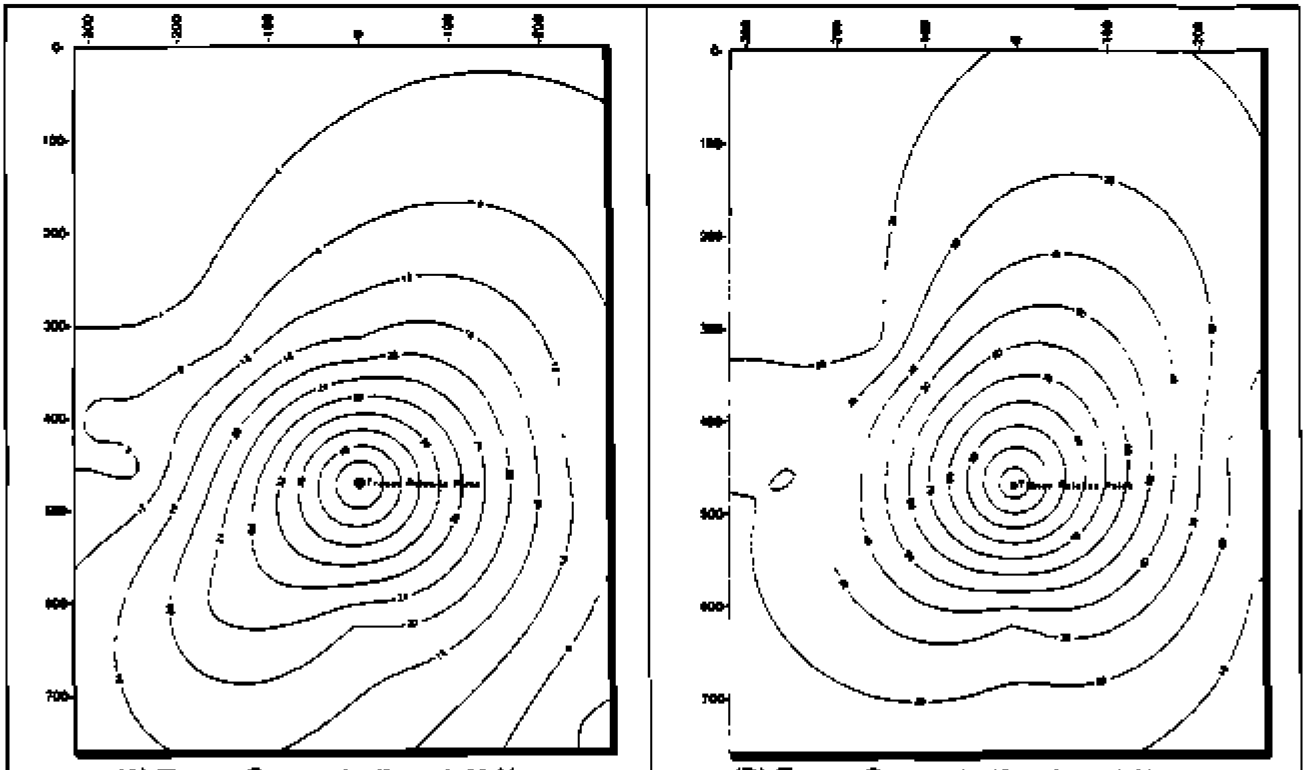
A series of 9 tests were conducted in STP to test various components and configuration of the sampling systems. The first two tests (STP-1 and STP-2) showed significant variation in the sample results. One of the problems identified was in the sensitivity of the gas-chromatograph's electron capture detector (ECD), requiring its replacement$^{(25)}$. However, as discussed above, several questions were raised by these first two tests and a decision was made to utilize the RSTC to assess system problems.

After correcting problems with the analytical system and modification of certain components, another test (STP-3) using a continuous release of BCF was used to baseline the system. Pump times were determined for each of the sampling stations and measurements taken until breakthrough equilibrium. STP-4 was similar to STP-3 except that each station was sampled repetitively at one-minute intervals to determine if repetitive sample withdrawal would affect concentration values.

STP-5 and STP-6 involved Freon-13B1 and Freon-12 tracers. STP-5 was aborted after complications with the tracer release system and STP-6 sampling data showed very little diffusion was occurring. After examination of possible causes for the test failures, it was decided that the tracer release line had become blocked as a result of soils shifting or compacting.

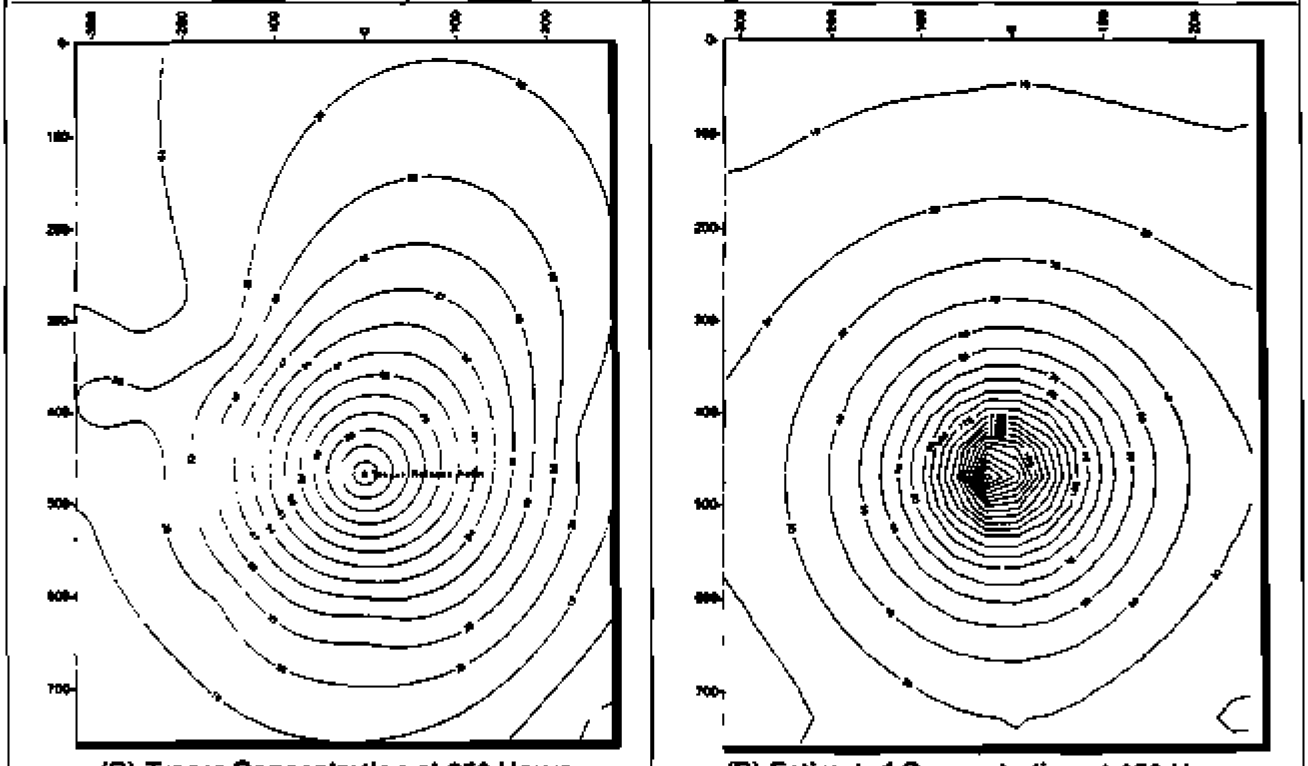
STP-7 was the first completely successful tracer test. Both $SF_6$ and Freon-13B1 were used. Both compounds were introduced at sampling station 152-037-475 with source strengths for 7.55 and 11.74 nanograms/s respectively for $SF_6$ and Freon-13B1$^{(26)}$. The test lasted for approximately 300 hours. Figures 4.5 and 4.6 present isopleth concentration lines for the two tracers. The data were analyzed using a krigging model and certain distortions in the concentration patterns are an artifact of the model. However, these figures do show the tracers exhibit a generally symmetrical pattern close to the release point with the predominant upward diffusion$^{(27)}$.

Figures 4.5 (d) and 4.6 (d) show the estimated concentration isopleths calculated using an analytical solution model compared with the sampling data at 152 hours. The modeling results closely compare with the sampling data at points close to the tracer release. The model assumed a homogeneous soil density and porosity and did not account for boundary conditions at the backfill interfaces$^{(27)}$. Therefore, the upward diffusion of tracers would be expected if the backfill materials were not compacted to original soil density.



(A) Tracer Concentration at 48 Hours

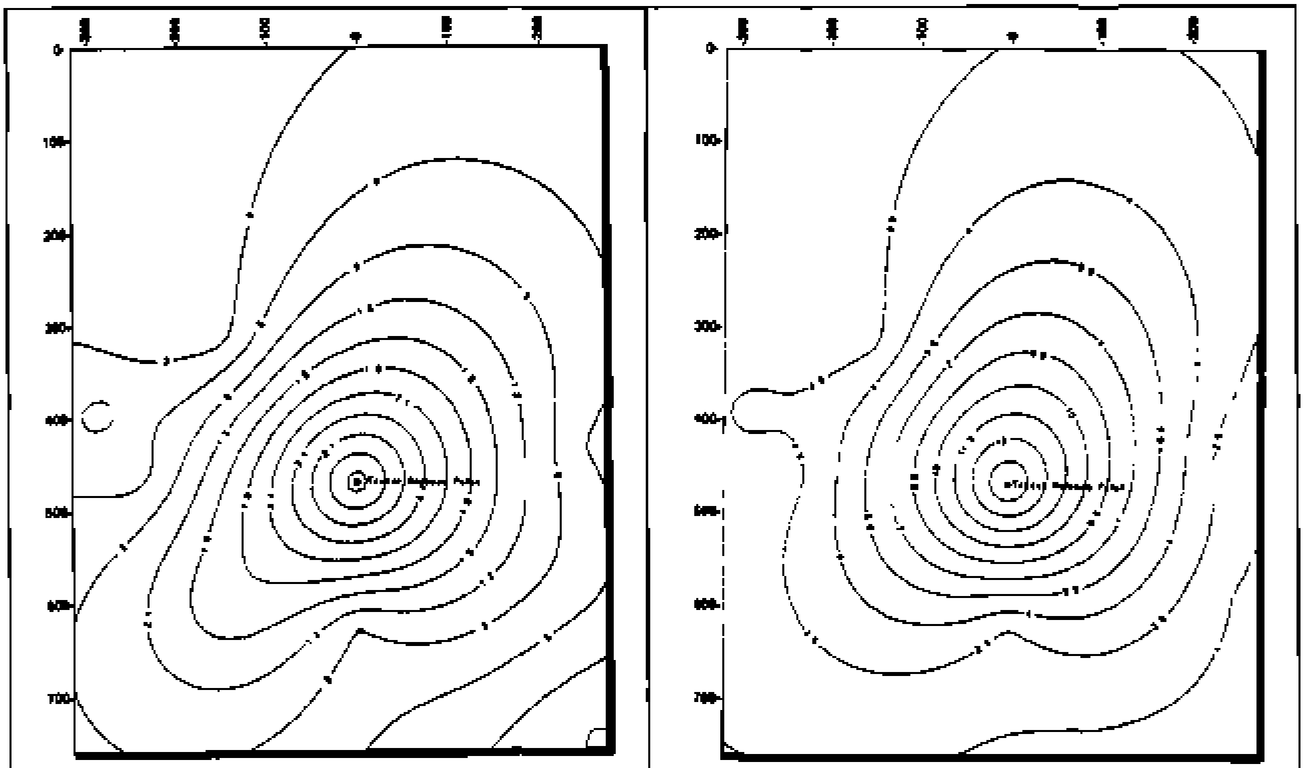
(B) Tracer Concentration At 152 Hours



(C) Tracer Concentration at 256 Hours

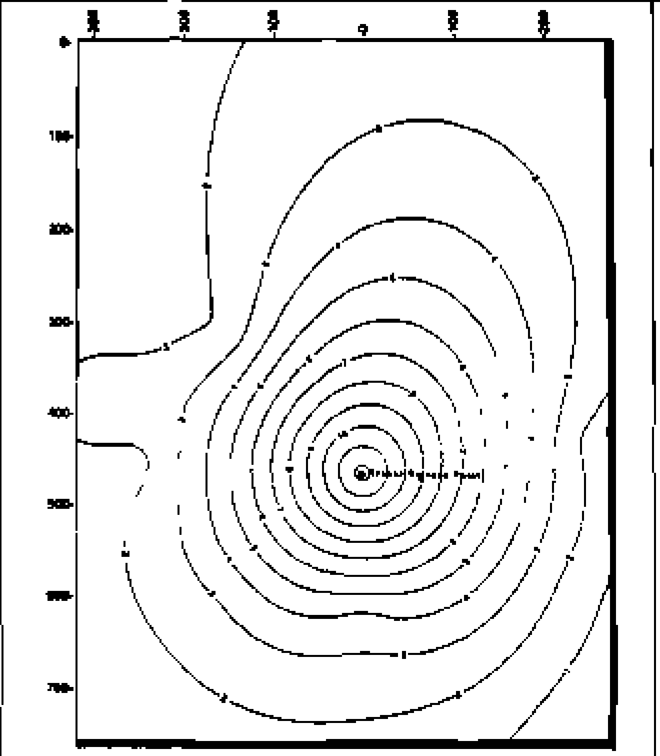
(D) Estimated Concentration at 152 Hours

FIGURE 4.5. STP7 F13B1 Tracer Contours (ppb)



(A) Tracer Concentration At 48 Hours

(B) Tracer Concentration At 152 Hours



(C) Tracer Concentration At 258 Hours

FIGURE 4.6. STP7 SF6 Tracer Contours (ppb)

The data obtained from STP-7 partially validate the diffusion model. Full validation would require modification of the model to account for boundary conditions.

STP-8 was a thermal "ramp-up" test. After completion of STP-7, the two 1000-watt heaters were activated to build up temperatures to over 100°C. During the period of temperature build-up, soil air samples were drawn to monitor tracer desorbtion from soils in STP. Temperatures stabilized after approximately 60 days of heating (See Figure 4.7)$^{(27)}$. During the heating period, soil moisture was monitored. As expected, heat build-up caused moisture to diffuse outward from the heat source.

STP-9 was the last test to be conducted. The test was carried out using the same tracers as STP-7 except under heated subsurface conditions. Figures 4.8 and 4.9 present the concentration and heat isopleths for the two tracers at various times. As can be seen from these figures, the diffusion direction was affected by both the upward migration through the backfill material and a horizontal component due to the heat radiating from the thermal sources.

The results from the STP tracer tests can be summarized as follows.

a. Many of the difficulties and errors associated with the sampling and analytical systems were identified. The system did provide useful data but requires skilled operators capable of interpreting analytical results and making system modifications.

b. The data collected verified the accuracy of, and partially validated, the diffusion model used to predicted tracer migration.

c. Composition and density of backfill materials affected the direction of gaseous material diffusion. As would be expected, the tracer gases followed the path of least resistance.

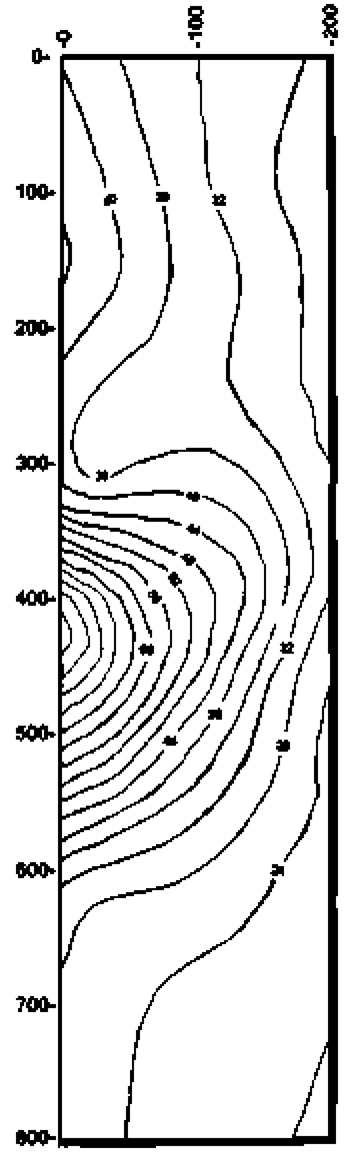
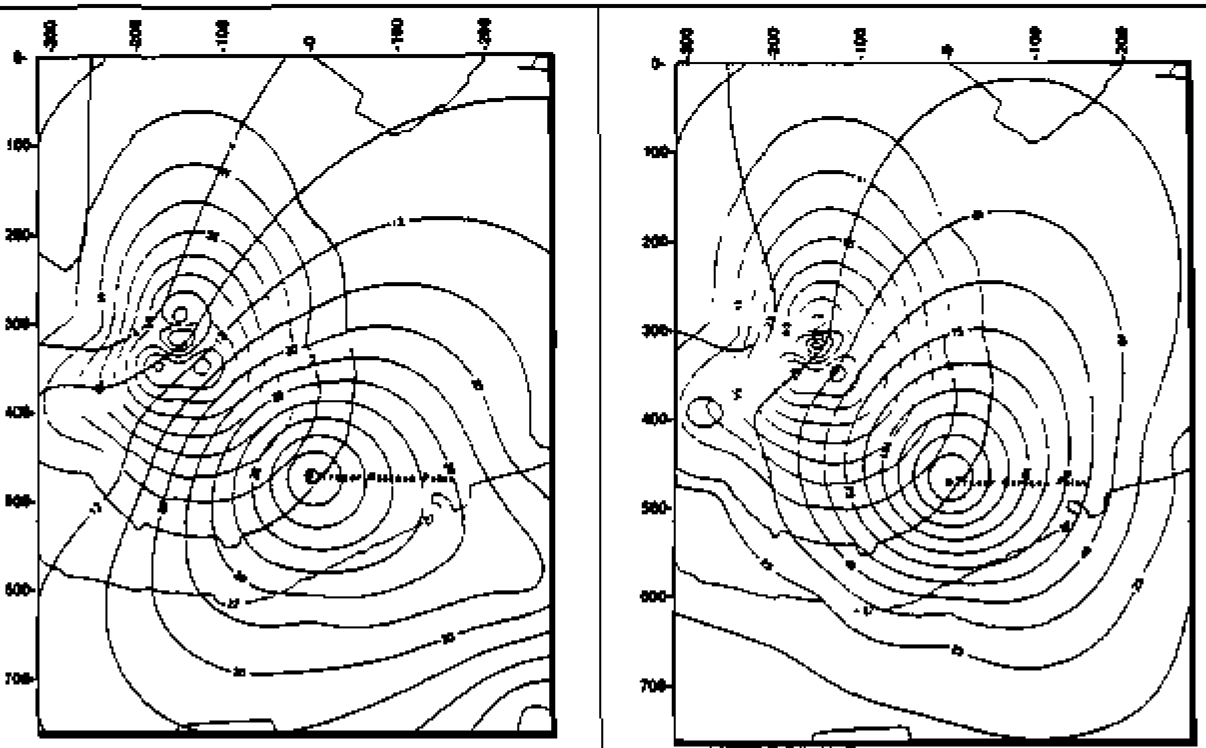


FIGURE 4.7. STP8 Temperature Contours

## 4.3 GCDT Tracer Tests

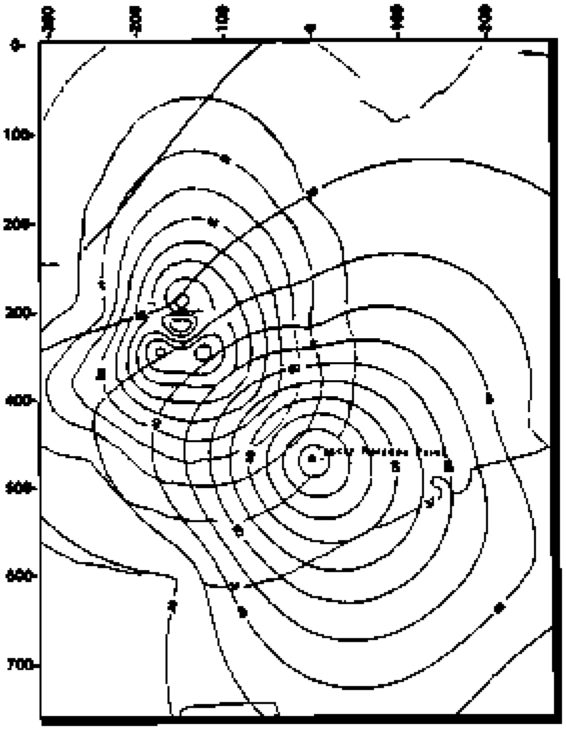
A series of 5 tracer and calibrations tests were conducted in GCDT. The first four tests were primarily to test components of the system and obtain performance characteristics of the sampling lines and stations. Several of the sampling stations were determined to be inoperative after these tests had been completed and were eliminated during subsequent testing.

The principal tracer test, GCDT-5, was started on November 5, 1986 and completed on January 23, 1987$^{(28)}$. Both $SF_6$ and Freon-13B1 were used. The $SF_6$ was released at a rate of 450 nanograms/minute at the 26-meter depth of line 279-080. This location was approximately 2.8-meters from the center of the emplacement shaft. The Freon-13B1 was released at



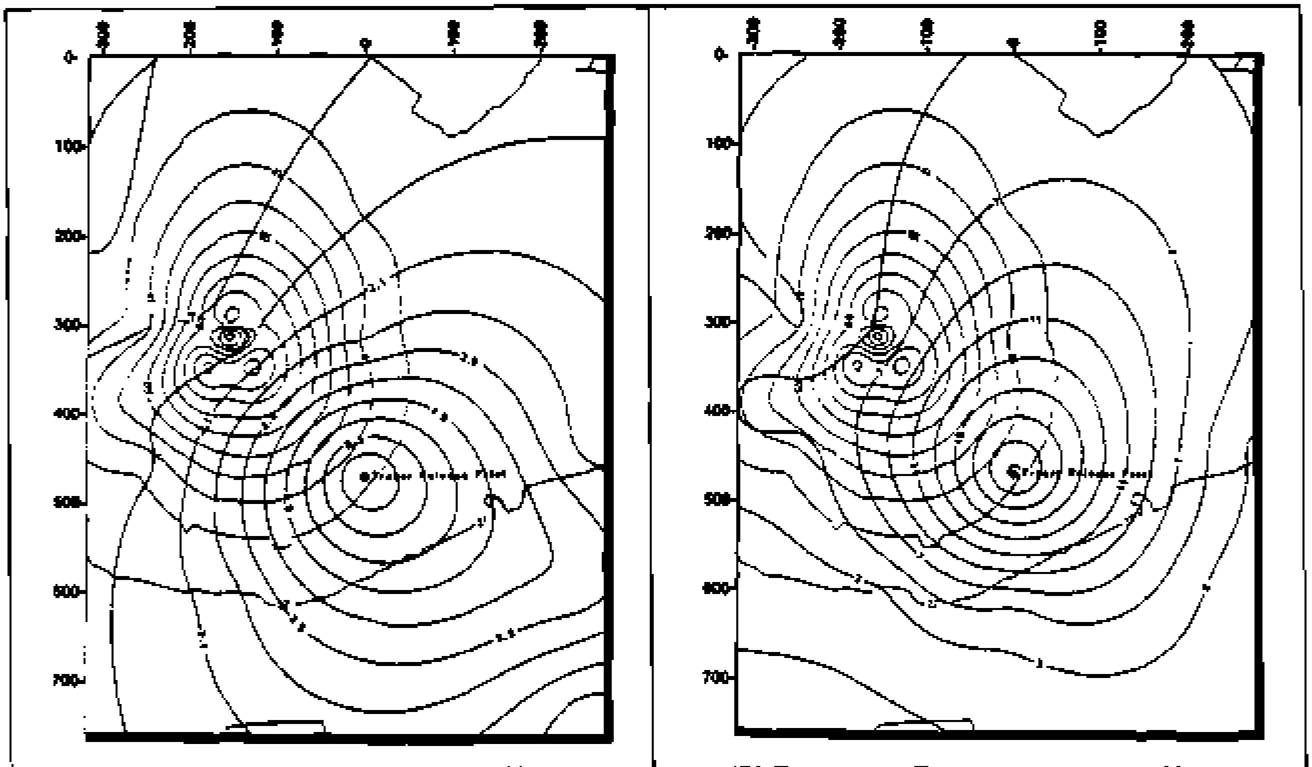
(A) Tracer and Temperature at 52 Hours

(B) Tracer and Temperature at 141 Hours



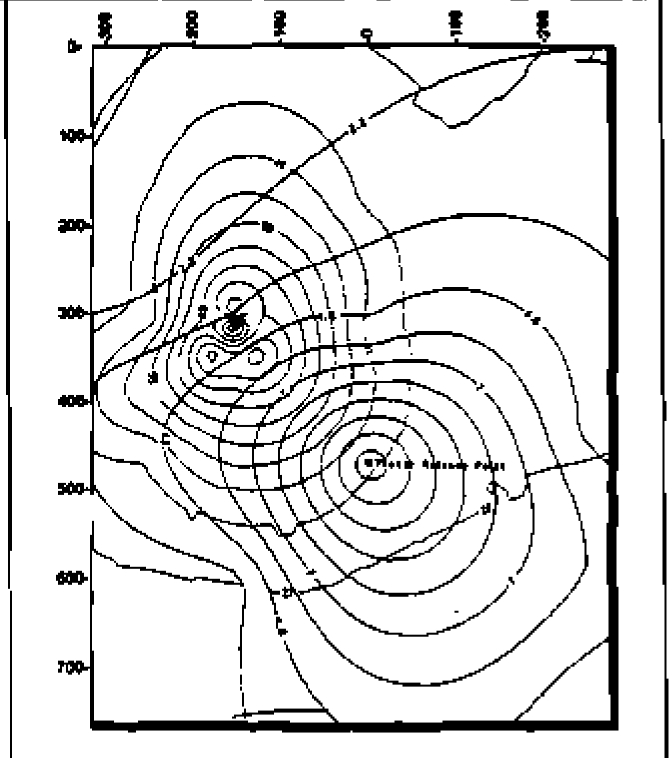
(C) Tracer and Temperature at 235 Hours

FIGURE 4.8. STP9 F13B1 Tracer and Temperature Distributions (ppb and °C)



(A) Tracer and Temperature at 52 Hours

(B) Tracer and Temperature at 141 Hours



(C) Tracer and Temperature at 235 Hours

FIGURE 4.9. STP9 SF6 Tracer and Temperature Distributions (ppb and °C)

a rate of 2085 nanograms/minute at the 18-meter depth of line 160-120 which is in the central emplacement shaft approximately 1.6-meters from the center. The purpose of releasing two tracers in different locations was to assess the migration across the horizontal soil boundaries and determine the migration characteristics of the tracers within the emplacement and monitoring shafts.

Interpreting the data from GCDT-5 proved complex and a variety of analytical methods were applied (see Appendix A). The complexity in the data derives primarily in the configuration of the GCDT and the density of the backfill materials. It was apparent that the tracers were not diffusing in a radial pattern and were following the path of least resistance within the backfill material. Based on the tests conducted in STP, this was expected to occur. However, as the tests continued and additional tracer material was added, the point injection source essentially became a line source. Therefore interpretation of the data required reevaluation of all data and use of a line source model[28].

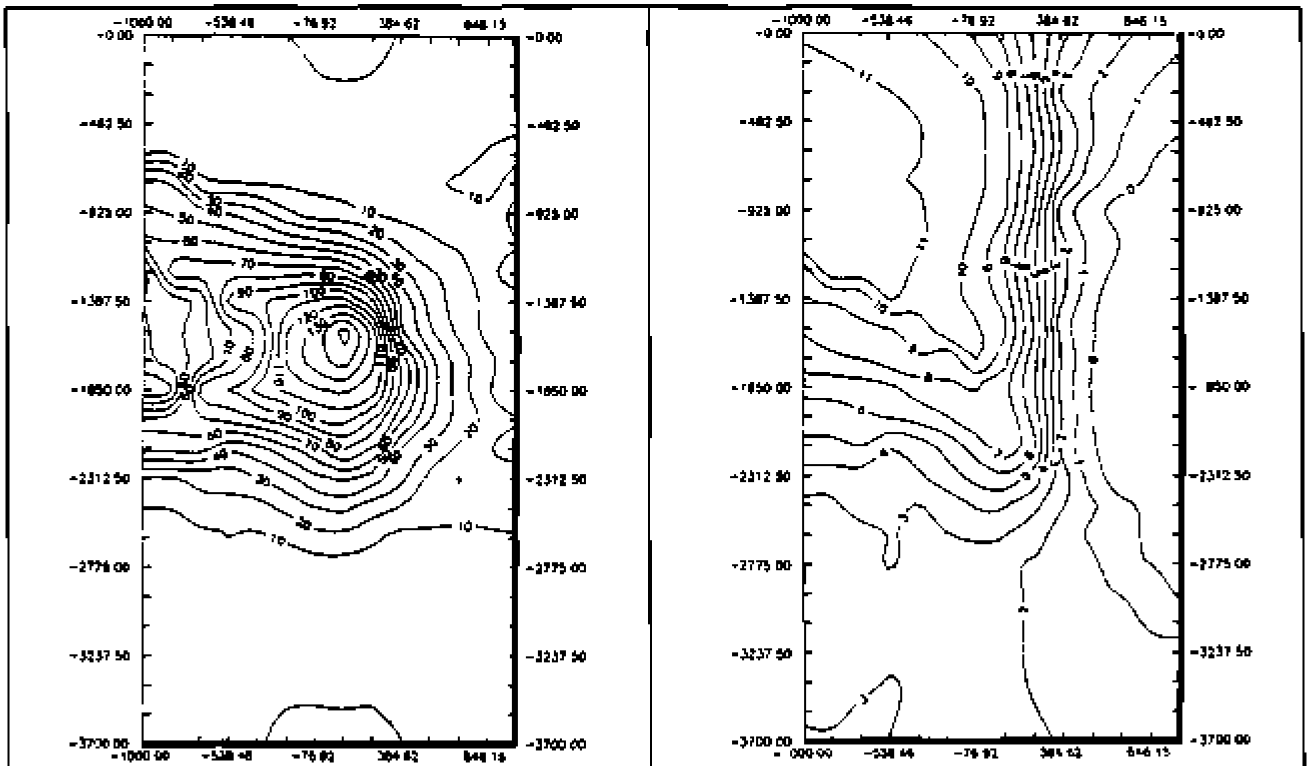
Figures 4.10 through 4.12 show the observed and expected tracer concentration profiles for Freon-13B1 at three time intervals. Figure 4.10 (a) shows the expected diffusion if a point source is assumed. The diffusion patterns are more closely aligned with the observed data (Figure 4.10 (c)) than the line source model profiles presented in Figure 4.10 (b). At later time intervals, the observed data for both Freon-13B1 and $SF_6$ begin to fit the expected line source model. Based on these data, the conclusion was that at early time intervals, the tracers were acting as a point source. As additional tracers diffused into the soils and concentrations became higher in the vertical backfill materials, the tracers begin to act as a line source.

Comparison of the Freon-13B1 observed concentration data to the predicted point source models shows an over-prediction of 120 ppb at 500 hours and 260 ppb at 1700 hours. Farther away from the sources the model over-predicts by 10 ppb at 500 hours and 40 ppb at 1700 hours. The line source model generally under-predicts the concentrations but the discrepancies are not as great. At 500 hours the differences are only 20 ppb at locations close to the source and less than 4 ppb further away from the source[28]. At later time intervals, the under-prediction increases to as much as 50 ppb close to the source. While neither model accurately predicts the tracer concentrations, the line model is a closer fit. It is assumed that some of the under-prediction of the line source model may be due to the effects of heat rising in the central emplacement shaft. Unfortunately, the contributions to diffusion rates due to thermal affects could not be analyzed using these models.

Figures 4.13 through 4.15 present both observed and predicted data for $SF_6$ point and line sources. For the $SF_6$ data, the observed data were contoured using two different methods. The first assumed a point source distributed as was used in the Freon-13B1 analyses, and the second assumed the data were distribution as a line source.

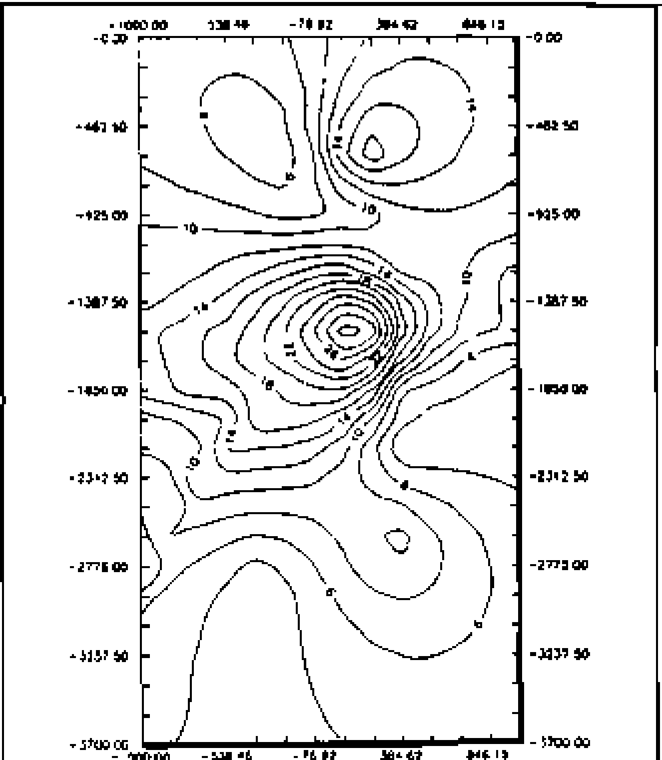
The line source predictive model more closely matches the data for both treatments of the observed data. At 500 hours the peak concentrations are under-predicted by 5 ppb and by 30 ppb at 1700 hours. At outlying regions, the under-prediction is only 0.5 to 2.0 ppb.

In comparing the results obtained from the two tracer data sets, it should be noted that the Freon-13B1 was released in the central emplacement shaft and therefore was diffusing in a 3-meter diameter hole compared to the 60-centimeter monitoring shaft for the $SF_6$. Also, temperatures around the $SF_6$ release point were approximately 20°C higher than for the Freon-13B1. This would account for the lateral shifting of $SF_6$ contour lines perpendicular to the heat sources which was not seen in the Freon-13B1 data.



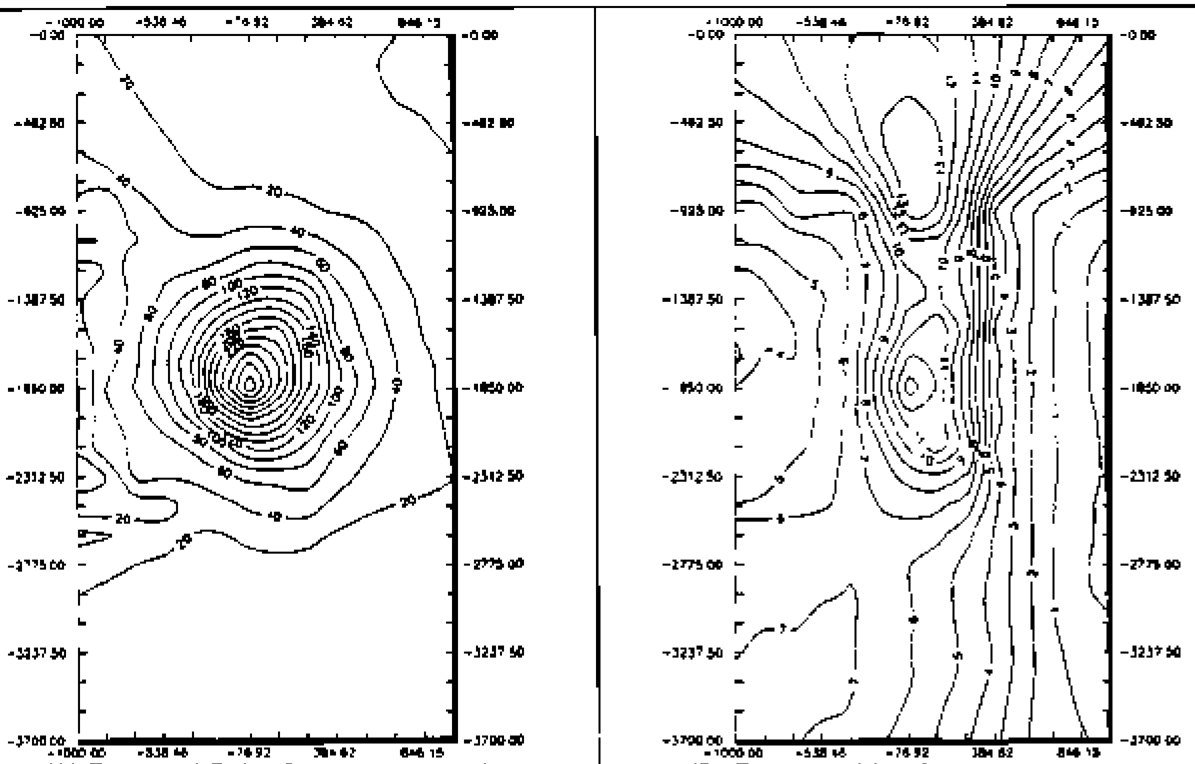
(A) Expected Point Source Distributions

(B) Expected Line Source Distributions



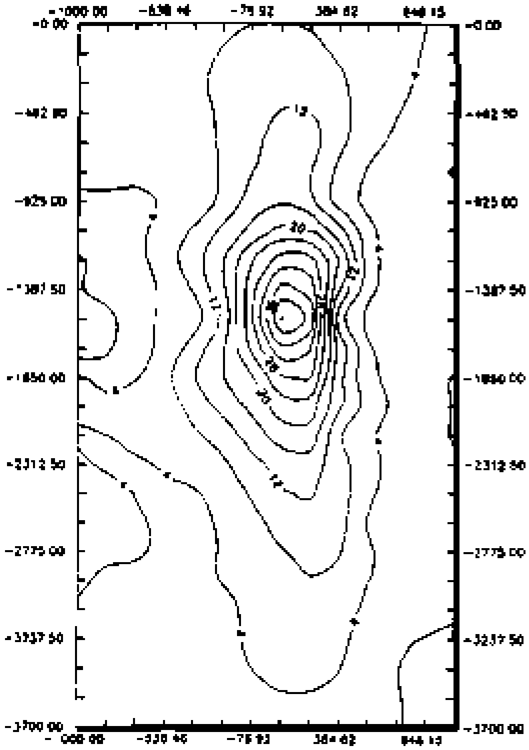
(C) Observed Source Distributions

FIGURE 4.10. GCDT5 F13B1 Tracer Contours at 500 Hours (ppb)



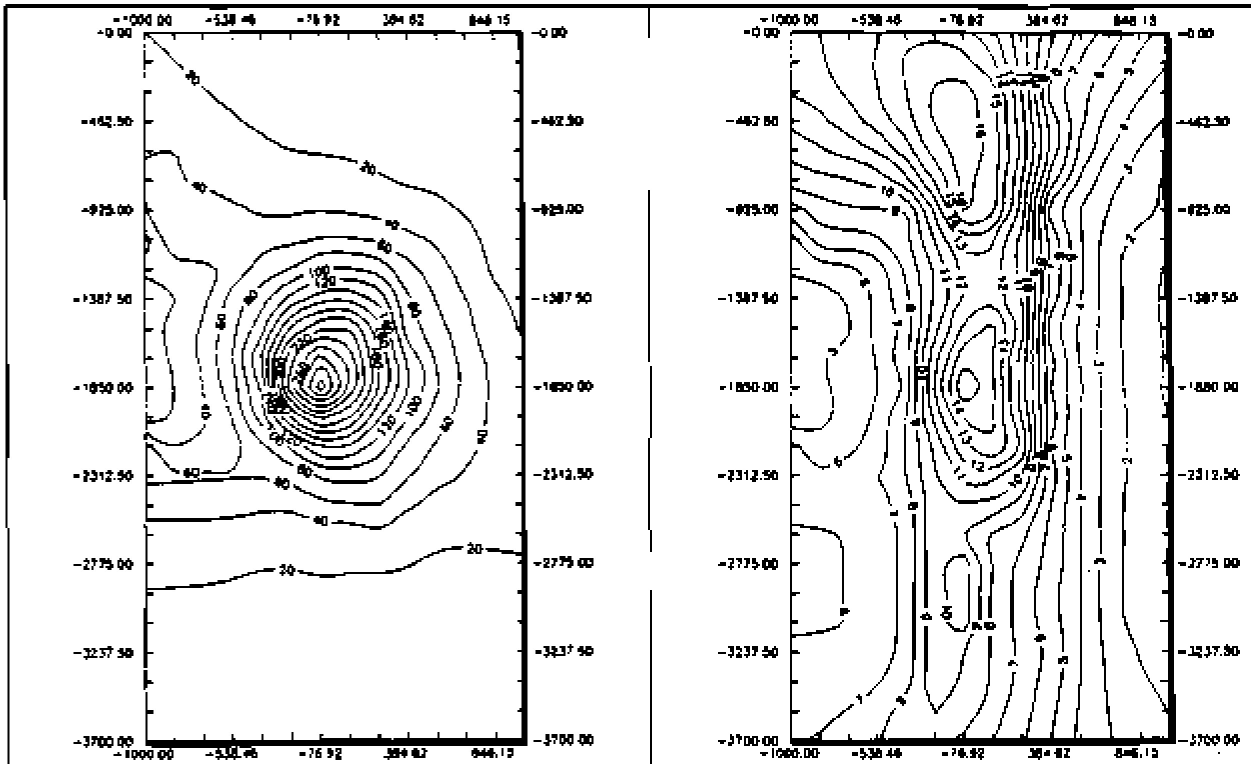
(A) Expected Point Source Distributions

(B) Expected Line Source Distributions



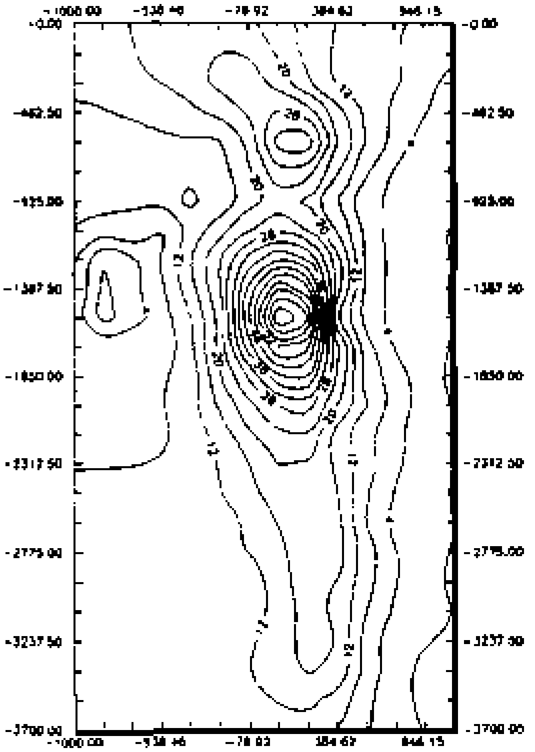
(C) Observed Source Distributions

FIGURE 4.11. GCDT5 F13B1 Tracer Contours at 1,000 Hours (ppb)



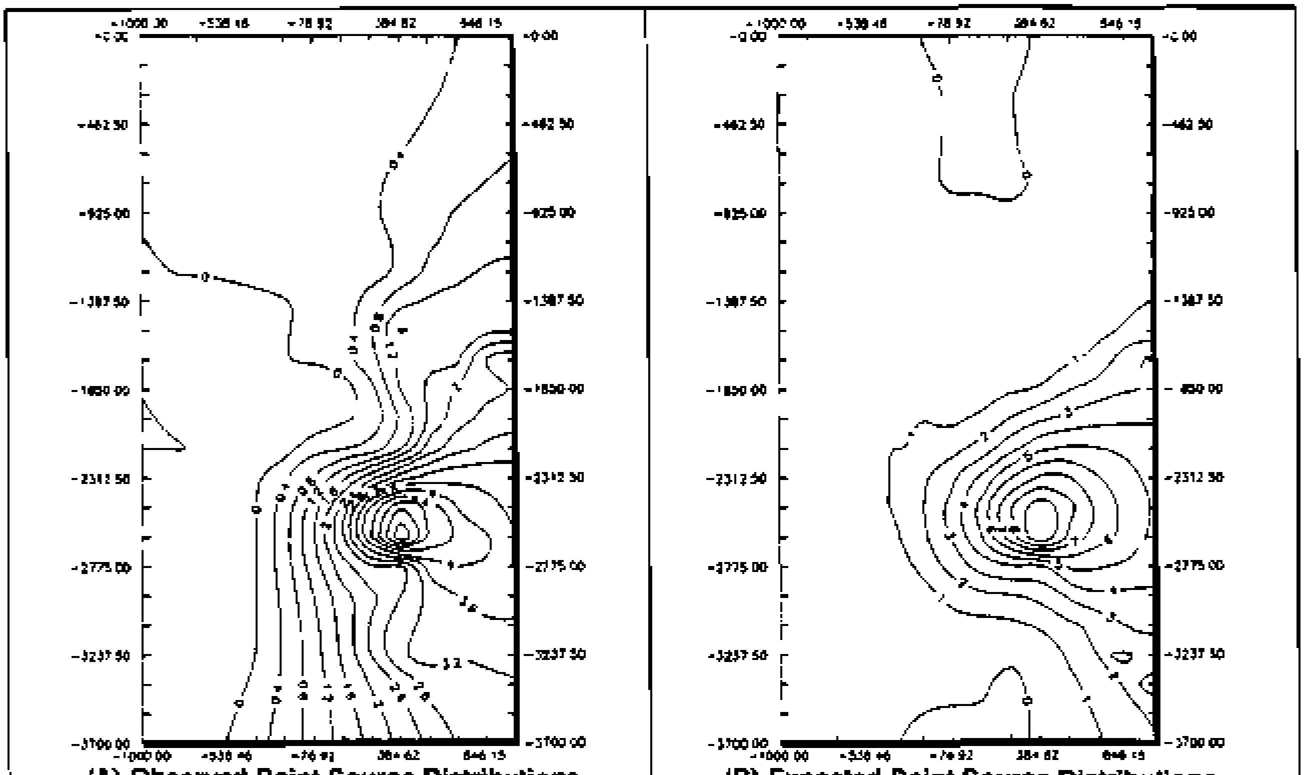
(A) Expected Point Source Distributions

(B) Expected Line Source Distributions

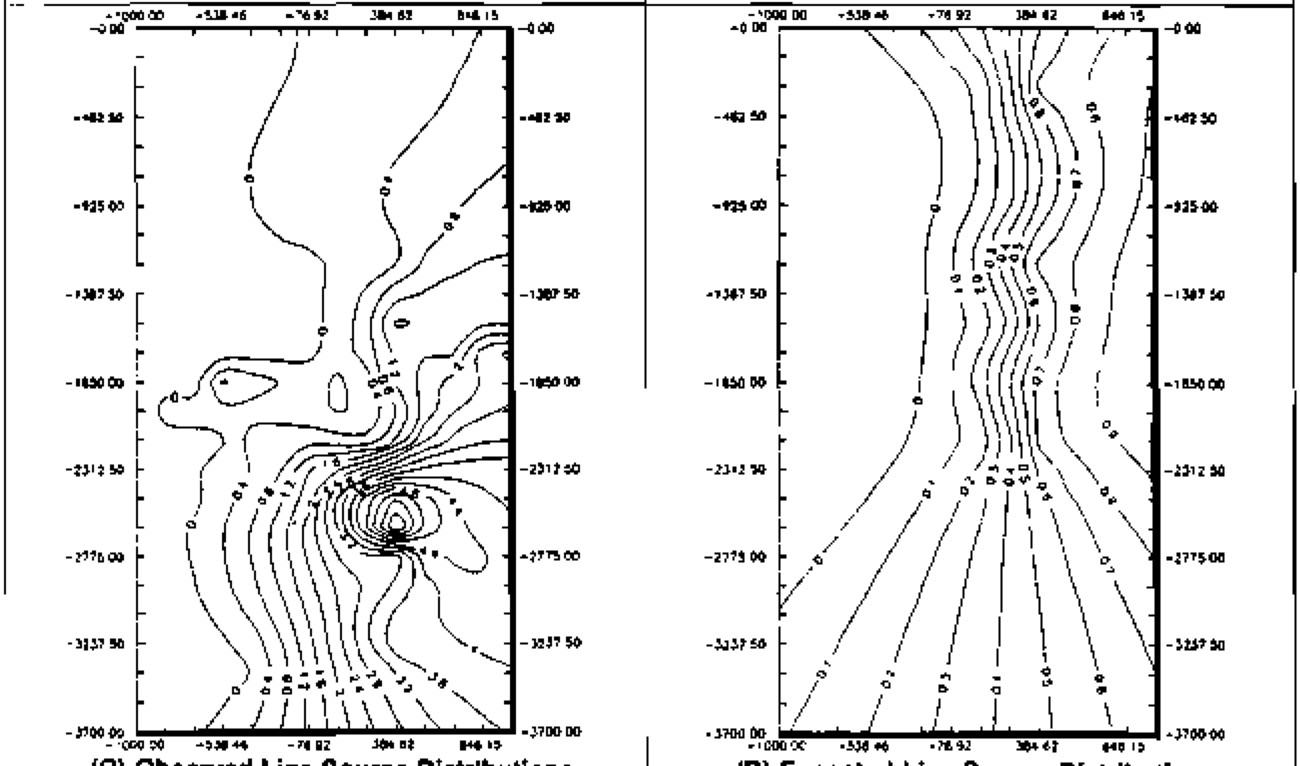


(C) Observed Source Distributions

FIGURE 4.12. GCDT5 F13B1 Tracer Contours at 1,700 Hours (ppb)

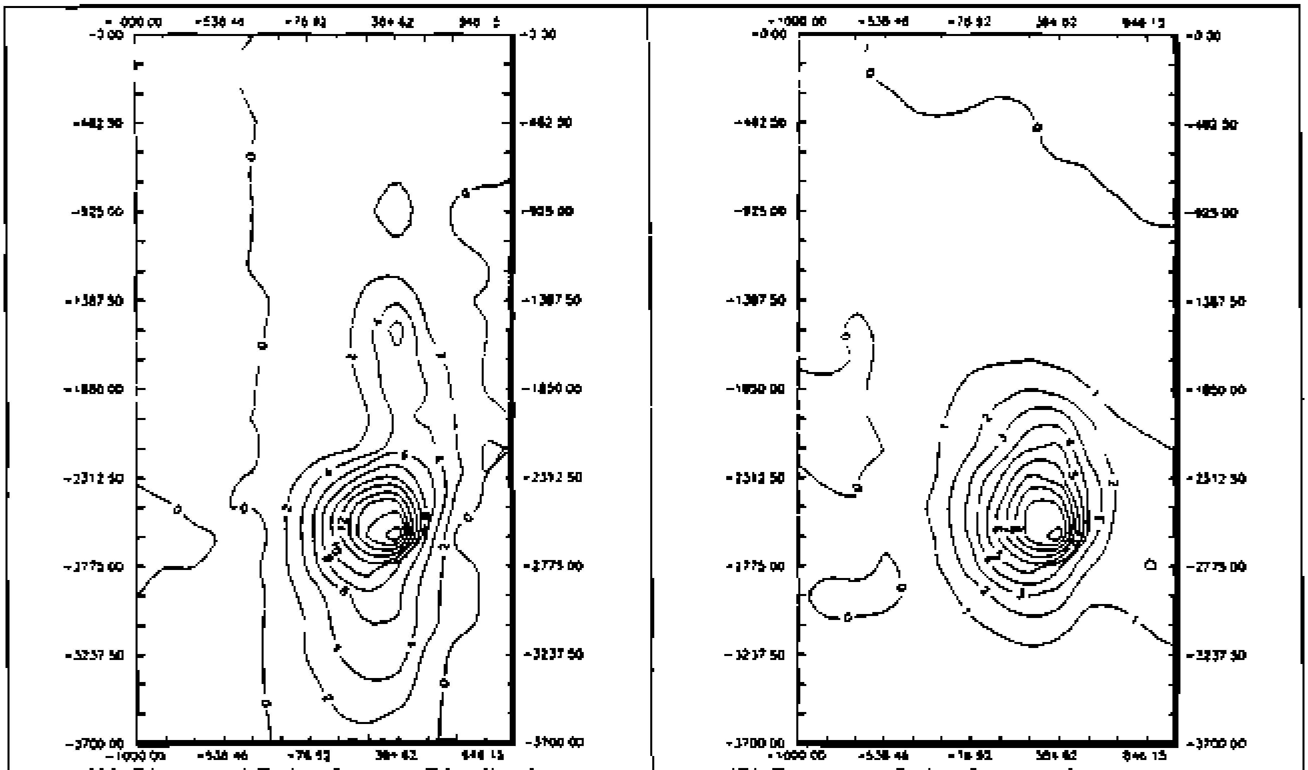


(A) Observed Point Source Distributions (B) Expected Point Source Distributions



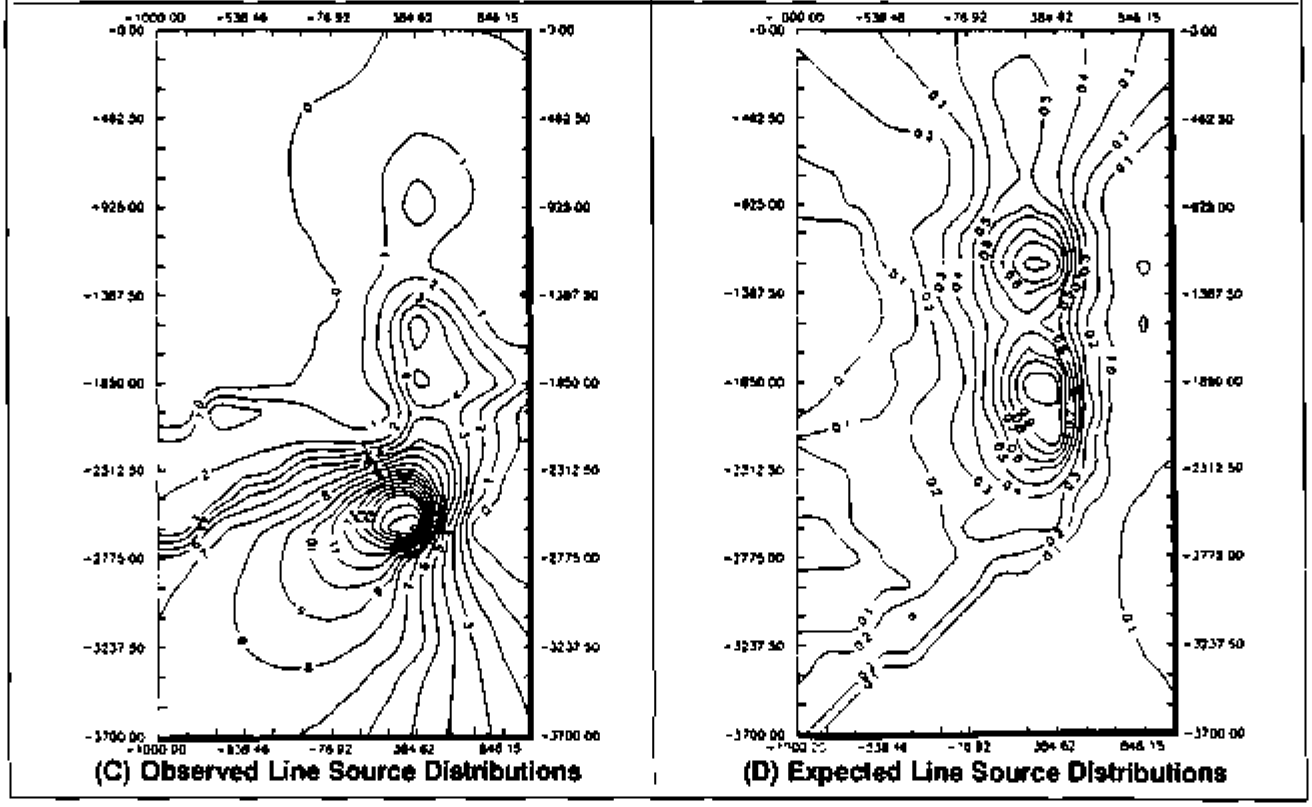
(C) Observed Line Source Distributions (D) Expected Line Source Distributions

FIGURE 4.13. GCDT5 SF6 Tracer Contours at 500 Hours (ppb)



(A) Observed Point Source Distributions

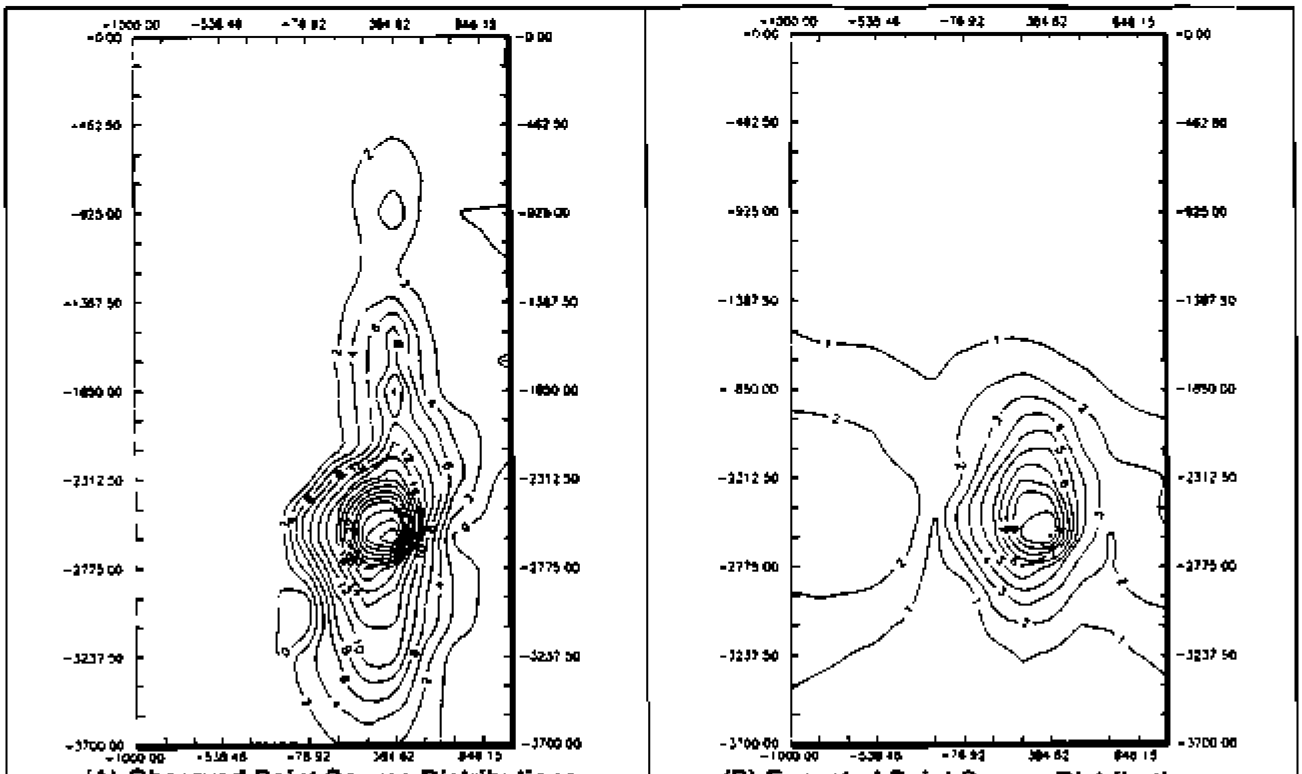
(B) Expected Point Source Distributions



(C) Observed Line Source Distributions

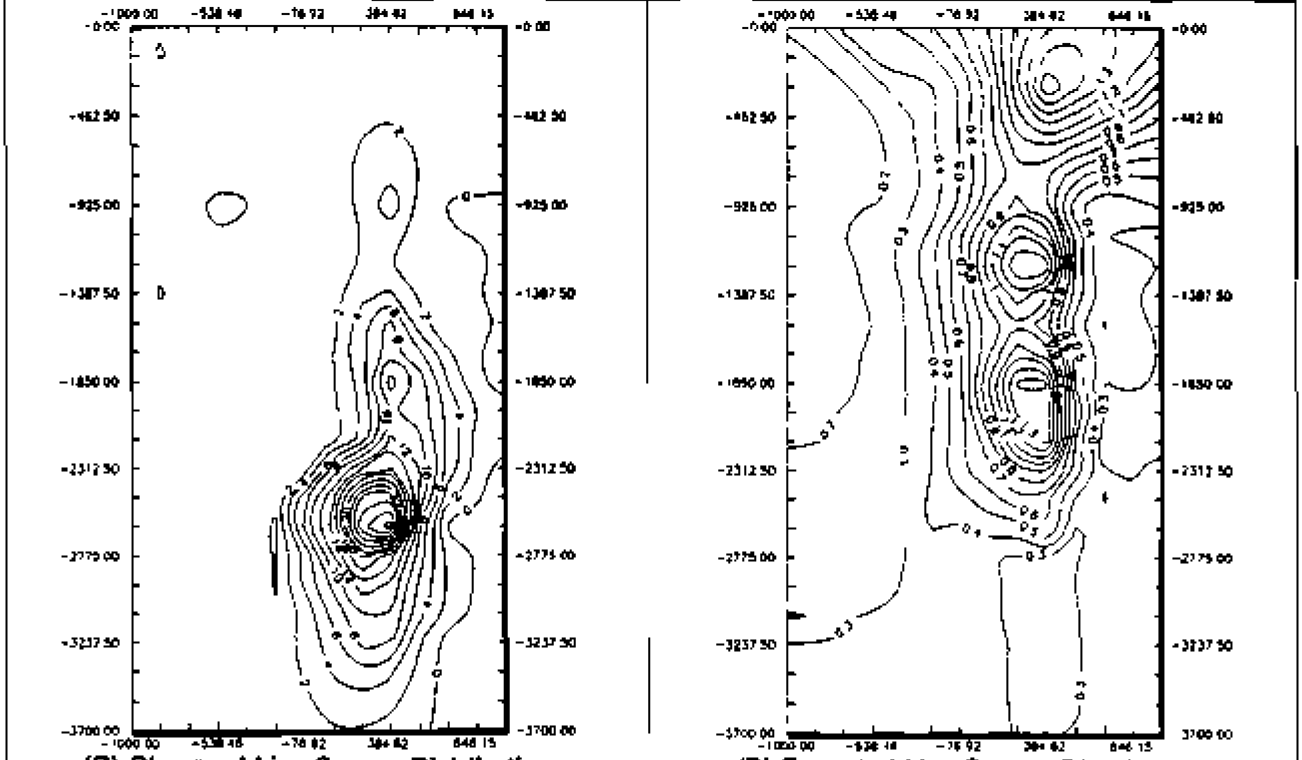
(D) Expected Line Source Distributions

FIGURE 4.14. GCDT5 SF6 Tracer Contours at 1,000 Hours (ppb)



(A) Observed Point Source Distributions

(B) Expected Point Source Distributions



(C) Observed Line Source Distributions

(D) Expected Line Source Distributions

FIGURE 4.15. GCDT5 SF6 Tracer Contours at 1,700 Hours (ppb)

## 4.4 Tritium Migration Studies

Upon completion of the tracer tests in GCDT, a investigation of tritium migration in GCDT was initiated. Several of same soil air sampling stations and lines were used as in the tracer test. One exception to the sampling system was that the 1/16-inch tubing was removed from each station and samples were continuously pumped from the lines. Soil air was passed across a cold trap to condense any tritiated water vapor. The purpose of these studies was not only to determine the release rates for tritium to the surrounding soils but to assess what the rates of release to the atmosphere were. These data are necessary to assess risks and migration potential associated with HSA tritium disposal in GCD.

The first results from these studies were received shortly before publication of this report (see Reference 36). The studies confirm results from the tracer experiments, showing upward migration through the backfill material. The rates of release to the surface are approximately 30 microcuries per day or approximately $10^{-10}$ of the inventory volume. These preliminary results indicate that GCDT is an effective method of managing HSA tritium wastes.

# 5.0 RISK ASSESSMENT ISSUES

During the course of GCDT, two separate studies were conducted to assess the risks associated with disposal of GTCC wastes at NTS. The first study was prepared in 1983 to address long-term risk scenarios and was based on preliminary design and inventory data[29]. The second study will be issued in 1988 and addresses operational accident scenarios and short term-consequence analyses and is based on data collected during waste loading operations[30].

This section summarizes the results of the two studies.

## 5.1 Operational Considerations

During GCD operations, the principal short-term risks are to operations personnel primarily from exposure during free-air transfer operations of HSA sources. To address these issues, a probabilistic risk assessment of waste handling operations was performed. The exposure scenarios were categorized as those during normal operations and those during off-normal operations. The normal operations scenarios evaluate the exposures from each disposal operation. The off-normal scenarios concern exposures when one or more items of equipment break down so that contingency plans must be executed. Of particular interest is a source suspended in mid-air and a source disconnected and dropped to the ground.

**5.1.1 Normal Operations.** There are two mechanisms for personnel exposure during normal operations. First, there is exposure to an individual within the controlled area. While safety procedures prohibit personnel from being outside the control room during waste loading operations, the worst case scenario assumes an individual to be located outside the control room. The second exposure pathway occurs during backfilling operations. The operator of the front-end loader enters the radiation field around the borehole to dump cover soil. The operator is trained to accomplish this task in a short time interval (about 2 minutes), in order to limit individual exposure. Doses for the 2 mechanisms were computed assuming the source term presented in Table 5.1[31].

The scattered radiation dose to an individual outside the control room was computed using the computer code SKYSHIN that was developed for the GCDT project[21]. The results for the 2 mechanisms, along with uncertainty bounds, were[32]:

| Mechanism | Expected Dose | 95% Upper Uncertainty |
|---|---|---|
| Scattered Radiation | 3.7 mrem | 4.5 mrem |
| Front-end Loader | 0.04 mrem | 0.07 mrem |

**5.1.2 Off-Normal Operations.** The term "off-normal" operations refers to an accident or rare event that has the potential for radiological exposure to personnel in the vicinity of the borehole. Atmospheric transport, direct gamma radiation, and sky shine radiation path-

**TABLE 5.1. Normal Operations Nuclide Inventory - Single Container**

| Nuclide | Curies |
|---|---|
| Co-60 | 167 |
| Sr-90 | 33,333 |
| Cs-137 | 8,333 |
| Ra-226 | 7 |
| | 41,840 |

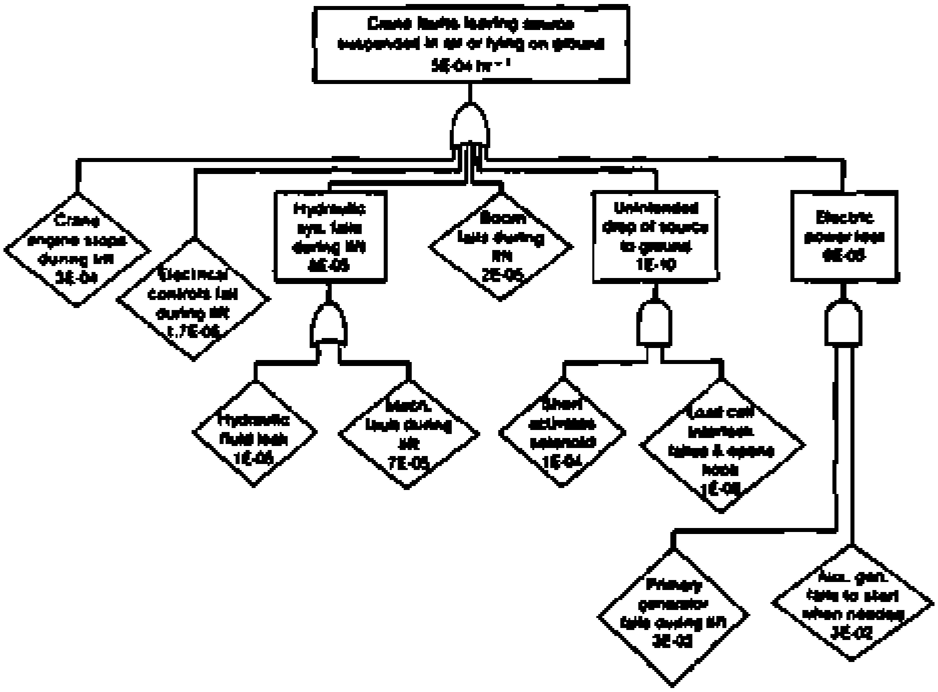


FIGURE 5.1. Failure Modes and Effects Analysis

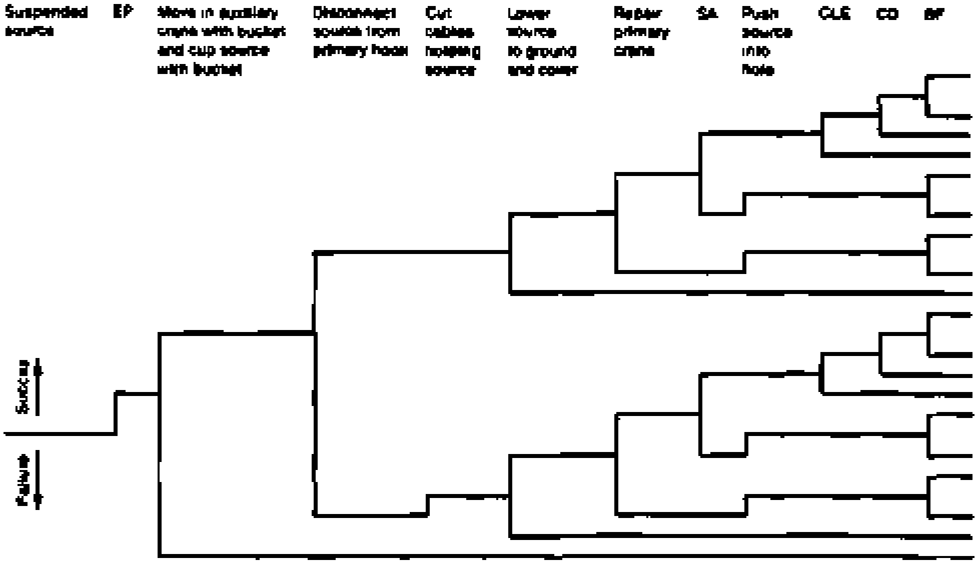


FIGURE 5.2. Event Tree for Suspended Source Scenario

ways were considered. The following off-normal release scenarios were selected for analysis.

1. Atmospheric transport after rupture of a source container.

2. Radiation from a suspended source after failure of the RWHS boom crane to lower or rotate the source into a shielded position.

3. Radiation from a dropped source after the failure of the grapple module tool or lifting attachments.

Using the source terms presented in Table 5.1, a release of 0.25 curies was assumed for the case of a ruptured container. The frequency of rupture was assumed to be $3 \times 10^{-6}$ per year. Five nuclide species were assumed to be in the container, uniformly distributed, the two largest fractions being for tritium and strontium-90. The estimated dose to individuals within 50 meters was 60 mrem. The 95th-upper uncertainty bound was estimated as 2880 mrem, mainly because of a release fraction uncertainty factor of 10. The risk of this scenario (that is, the probability weighted dose) was $2 \times 10^{-4}$ mrem/year ($9 \times 10^{-3}$ mrem/y upper bound)[33].

In order to develop hazard and probability models for the suspended source and dropped source scenarios, events that could cause the scenarios were developed. These were sought using a technique from the discipline of reliability engineering known as failure modes and effect analysis (FMEA)[33,34]. The results from the FMEA are summarized in a tree diagram in Figure 5.1. Figure 5.1 should not be construed as a rigorous fault tree. In order to develop the probability models, event trees were drawn to provide the interrelationships of various failure events after the initiating event and their associated contingency plans. For example, if it turns out to be too difficult to repair the primary crane after the initiating event, the plan is to push the source into the disposal hole using the front-end loader. The event tree for the suspended source scenario is shown in Figure 5.2.

The probabilities for each of the steps in the event tree were estimated from the literature so that the probability for each limb could be estimated. (It may be noted that human error is not included because the uncertainties of step probabilities are large enough to encompass the operator errors.) The dose to an individual involved in each step was also estimated using the nuclide inventory presented in Table 5.1. Finally, an average was computed for each of the two initiating events. These were 1245 mrem for the dropped source and 1247 mrem for the suspended source. It is important to know that these numbers are not maximum individual doses because no one person is involved in all steps. This is particularly true for the mechanics involved in repairing the primary crane in a radiation field because these people would be rotated out of the job in accordance with prescribed health physics procedures. Finally, an uncertainty analysis was completed taking into account that many of the events were dependent. The results for both the dropped source and the suspended source for the 95th-uncertainty bounds were 4140 mrem[30].

Results of the occupational risk analysis are summarized in Table 5.2. From this table and other intermediate results, it is concluded that the suspended source scenario is the most serious, especially for crane repair mechanics and for front-end loader operators. It may also be observed that the ruptured container scenario can cause individual exposures approaching 3 rem, depending on how much the nuclide distribution and the release quantity deviate from the nominal values.

## 5.2 Short-Term Consequence Analysis

The issue of short-term tritium releases was addressed by EG&G Idaho[33]. At the time the study was conducted, there was insufficient information available to allow realistic modeling of the tritium release at the soil surface. Instead, an upper bound model was developed. This upper bound model assumed 203 drums buried in a 10-feet diameter borehole. Each drum was assumed to have a release rate of approximately $1.7 \times 10^{-3}$ micro Ci/h in accordance with a report by Mound Laboratories. The released activity was assumed to arrive at the soil surface at the same rate. This was the source term for an airborne transport model that assumed a constant wind velocity toward Las Vegas at 3.6 meters/s (8 miles per hour). Doses to the people exposed to this plume were calculated and are shown in Table 5.3.

## 5.3 Long-Term Risk Assessment

Long-term risks issues were evaluated using scenario based assessments rather than functional analysis.

## TABLE 5.2. Summary of On-Site Occupational Dose Scenarios

| Scenario | Individual Nominal Dose (mrem) | Dose Uncertainty 95th Percentile (mrem) | Individual Nominal Risk (mrem) | Dose Uncertainty 95th Percentile (mrem) |
|---|---|---|---|---|
| Normal container lift and emplacement, each | 3.7 | 4.5 | | |
| Normal backfilling, each | 0.04 | 0.07 | | |
| Suspended source | 1247 | 4140 | 0.06<br>(per lift) | 0.29<br>(per lift) |
| Dropped source | 1245 | 4140 | $10^{-8}$<br>(per lift) | $2 \times 10^{-7}$<br>(per lift) |
| Ruptured container | 60 | 2880 | $2 \times 10^{-4}$<br>(per year) | $9 \times 10^{-3}$<br>(per year) |

## TABLE 5.3. Computed Doses Due to Steady State Tritium Release

| | Dose (mrem/y) | |
|---|---|---|
| Location | Maximum Individual | Cumulative Population |
| NTS Field ( km) | $9 \times 10^{-3}$ | |
| Mercury (25 km) | $5 \times 10^{-3}$ | 4.3 |
| Indian Springs (50 km) | $2 \times 10^{-3}$ | 3.6 |
| Agriculture Areas (75 km) | $1 \times 10^{-3}$ | 3.9 |
| Las Vegas (110 km) | $3 \times 10^{-5}$ | 14.8 |
| | SUM: | 26.6 |

Each scenario was modeled using the RADTRAN radionuclide transport code to assess dose/risk to individuals and populations over a 1000-year period. In the report by Hunter[29], four basic scenarios were considered:

**Reference Case** - Base case with normal periodic precipitation and infiltration conditions.

**Climatic Change** - Near-term climatic change with precipitation ten times normal rates.

**Farmer/Intruder** - Intrusion scenario assuming development of a farm directly above the disposal site.

**Inundation** - Worst case groundwater transport scenario which assumes wastes become submerged through formation of lake immediately adjacent to the disposal site.

For purposes of comparison, the model was run both GCD and SLD scenario. In each case, the same waste inventory was used. Table 5.2 summarizes the result of the modeling. It should be noted that very conservative factors were used in modeling each scenario, tending to overestimate risks. For example, it was assumed that climatic changes, intrusion, and inundation occurred immediately after the end of institutional control (100 years). At this point in time, the majority of the HSA inventory has decayed less than three half-lives.

The only scenario which resulted in appreciable doses was the worst case inundation scenario. In this scenario it is assumed that the waste disposal zone has become saturated and that a drinking water well is placed on the site boundary downgradient from the groundwater flow direction. The majority of the dose in this scenario is attributable to strontium-90 and results from ingestion of the drinking water.

## TABLE 5.4. SUMMARY OF THE DOSE AND HEALTH RISKS RESULTING FROM 1000-YEAR RELEASE SCENARIOS

(Adapted From Ref. 29)

| Scenario/Disposal Method | Event Frequency ($y^{-1}$) | Maximum Individual[a] Dose Risk (rem/y) | Maximum Individual[a] Health Risk[b] (health effects/y) | Population Dose Risk (person-rem/y) | Population Health Risk[b] (health effects/y) |
|---|---|---|---|---|---|
| **Reference - Arid** | | | | | |
| SLB | 1E+0 | 4E-2 | 1E-5 | 8E-1 | 2E-4 |
| GCD | 1E+0 | 0 | 0 | 0 | 0 |
| **Climate Change - Humid** | | | | | |
| SLB | 1E+3 | 2E-6 | 6E-10 | 3E-5 | 9E-9 |
| GCD | 1E-3 | 0 | 0 | 0 | 0 |
| **Farmer/Intruder** | | | | | |
| SLB[c] | 1E-5 | 6E-3 | 2E-6 | 1E-1 | 3E-5 |
| GCD | 5E-7 | 0 | 0 | 0 | 0 |
| **Inundation** | | | | | |
| SLB | 1E-5 | 5E-3 | 2E-6 | 3E+1 | 9E-3 |
| GCD | 1E-5 | 5E-3 | 2E-6 | 3E-1 | 9E-5 |

(a) Maximum individual is a hypothetical person located at point of maximum dose consequence.

(b) Health risk (health effects/y) is combined cancer deaths and genetic defects per year, which equals $3 \times 10^{-4}$ health effects/dose unit multiplied by the annual dose risk.

(c) The farmer/intruder dose is the result of a container of waste being plowed up. The probability is a function of the area contaminated and the depth of the material disposed. Dose to farmer is from 40 hours exposure. Release to farmer occurs in 2095.

# 6.0 CONCLUSIONS AND LESSONS LEARNED

The GCDT was a successful project and the information gained has already been incorporated into operations at the NTS. GCDT has also contributed to the development procedures for management of HSA and GTCC wastes. Perhaps the greatest measure of success for this project was the immediate transfer of technology to the management of numerous Defense HSA LLW. In many instances, these wastes could not have been disposed of in conventional SLD without risks of exposure to personnel. However, as with all research projects, there were some aspects of the GCDT that would have been done differently had the investigators known the problems they would encounter. But the process of trial, error, and resolution is important part of any research program and investigators realize that it is difficult to achieve complete success in every aspect of the program.

## 6.1 Evaluation of Waste Handling Operations

Certainly one of the most notable and important achievements of the GCDT was in the development of handling systems for highly radioactive wastes and minimizing personnel exposures. The HSA strontium, cesium, and cobalt encapsulated sources disposed in GCDT presented a significant risk to personnel. The fact that these materials were disposed of without any recordable exposures and in a cost-effective manner, is the keeping with the best principals of ALARA.

In developing concepts for a remote waste handling system, the investigators were influenced by the need to have a system capable performing a variety of functions both at GCDT as well as in other site operations. The decision to modify an 18-ton all terrain crane was based on two principal factors: (1) the crane would be of use in other operations at the site, and (2) existing cranes at other LLW facilities could be easily modified for remote operations if GCD was to be implemented at those sites. The RWHS proved to be highly successful and the technology readily transferable to other sites.

It should be noted that both the skill of the RWHS operators and the substantial training they received in use of the systems were major contributors to the success of the operations. Also, it must be strongly emphasized that extensive planning and practice for each remote handled source were fundamental to success.

The lessons learned from the GCDT HSA waste handling operations have already been implemented and incorporated into standard practice at NTS. In the four years since the completion of GCDT waste loading, the RWHS has been used many times for remote handling of sources as well as normal daily operations. In fact, to date there have been over 100 remote handling GCD operations conducted at the NTS without a single recordable exposure to personnel. Given the risks associated with the handling of HSA sources, and compared with operations at other LLW sites, this is a significant accomplishment.

## 6.2 Evaluation of Monitoring Systems and Tracer Tests

The original experimental plan for GCDT called for the monitoring of heat and moisture in the disposal zone. The plan was later modified to incorporate use of tracers to assess facility performance. While the monitoring systems used in GCDT obtained the required data, problems experienced with certain system components would today, result in a significantly different system design.

**6.2.1 Soil Moisture Monitoring.** The most reliable moisture data collected was from the neutron moisture probe and in retrospect, additional neutron access holes would have been desirable. However, the data obtained adequately demonstrate the moisture flux away from the heat source and show that infiltration of precipitation is not a significant transport mechanism.

Data from the TCPs proved. unsatisfactory and of limited use. This is largely due to the complex electrical TCP reader/recorder and the extremely dry soil conditions of GCDT. The dryness of the soils and backfill material and later, heat from the thermal waste sources, prevented establishment of an equilibrium background for most of the TCP monitoring stations. Another factor was the installation and operation of RDAS. As discussed earlier, the RDAS was proto-typical and problems with the system were never completely resolved. This may have been partly due to system design, but lack of a stable background was probably the major contributor to erratic readings. In summary, the lessons learned were:

a. TCPs proved to be inappropriate for monitoring of soil moisture in the dry and unstable thermal environments of the GCDT.

b. The RDAS was a good concept but insufficient time and development funds were available to resolve system problems.

c. Neutron moisture probes proved to be the simplest and most reliable method for obtaining moisture data.

**6.2.2 Temperature Monitoring.** The Type J thermocouples used in GCDT provided the most reliable temperature data. The temperature probes on the TCPs did provide some data but the thermocouples proved to be the most satisfactory. Over 80% of the Type J thermocouples continue to provide usable data. The thermocouples closest to the heat source were designed to be "sacrificial" and not expected to perform over the life of the project. Calculational estimates of heating effects in the disposal zone showed temperature reaching 600 °C and would have required the development and fabrication of thermocouples with ceramic coatings 4 to 10 meters in length. While this may have been achievable, both the expense and long-term reliability of the monitors were questionable. Therefore it was decided that monitoring of heating in the disposal zone could be achieved by both the sacrificial thermocouples and through extrapolation from other temperature monitoring stations.

While it would have been preferable to have actual, rather than extrapolated, peak temperature data for the GCDT waste zone, the monitoring system did perform as intended and usable data continue to be collected.

**6.2.3 Soil Gas Sampling System.** As discussed earlier in Section 4, the soil gas sampling system was originally designed to collect tritiated moisture vapor. Teflon tubing, rather than copper or stainless steel, was used to reduce the weight on the suspended monitoring lines and reduce potential for crimping of lines during handling. This design was suitable for its original purpose but teflon tubing is not the desired material for conducting tracer tests. Teflon will sorb the fluorocarbon tracers and introduce a sampling error which results in the need to constantly recalibrate the system.

The GCDT investigators recognized the difficulties that would be encountered with modifying the soil gas sampling systems for tracer testing and steps were taken to mitigate those problems. While the sampling system did perform adequately, an all stainless steel system would have been preferred. It should be noted that the system is still being used for tritium monitoring experiments.

**6.2.4 Tracer Testing.** The tracer tests provided important data on the diffusion patterns in the soils around STP and GCDT. The tracer data show that the principal transport mechanism and pathway is through the backfill materials. Downward migration and horizontal movement through undisturbed soils is limited and not considered to be an important pathway of concern in the long-term performance of GCD at NTS.

While not all aspects of the tracer tests were completely successful the trial, error, and resolution process in developing a system have proven to be important. The information gained from the GCDT tracer experiments has been shared with government agencies, universities, and commercial companies investigating the applications of tracers in leak detection and characterization of spill sites. In addition, the lessons learned have already been applied in development of monitoring systems for a mixed waste facility at NTS, investigation of a fuel leak, and in validation of diffusion models.

## 6.3 Evaluation of Modeling Studies

A variety of modeling studies were conducted over the course of GCDT. While the results of some of these studies are notable accomplishments, the development of an appropriate performance model proved to be frustrating. This was largely due to the fact that early in the project, it was decided that when ever possible existing models would be modified and new models would be only be developed to address those unique aspects of GCDT (*eg.* radiation scatter from waste loading). While this is a logical approach, it also assumes that models exist that can be reasonably modified to meet the needs of GCDT. This proved to be incorrect and a substantial effort was made to modify an existing model before an alternative course of action was taken.

**6.3.1 Performance Modeling.** Early in the project, a survey of models which would be appropriate for use in modeling GCDT was conducted. There were two basic criteria: (1) the model must include both mass and heat transport, and (2) the model must address unsaturated flow and gaseous diffusion. Of the models surveyed, only the WAFE code developed by Los Alamos National Laboratory (LANL) met these requirements[35]. Some initial studies of GCDT using WAFE were performed by LANL and it appeared that the model would meet the project needs.

The principal problem with use of the WAFE code in GCDT was in the lack of sufficient documentation in both the operation of the model and interpretation of results. A significant effort was made to modify the WAFE code but the complexity of both the model and the necessary modifications were difficult to verify. Therefore efforts were re-directed towards simpler models which could address components of the system performance. The models used were analytical diffusion and kriging models which utilized data collected from GCDT monitoring systems and tracer tests.

The results of these modeling studies were satisfactory in analyzing the individual heat, moisture, and tracer material transport properties of GCDT. While a total systems model for GCDT was not developed, the studies that were conducted successfully met the performance modeling goals for the project and the lessons learned are valuable for consideration in future projects.

a. The GCDT was a unique facility and required development of a unique performance model. The modification of an existing model is usually assumed to be the most time efficient and cost effective. More detailed analyses of the model and the modification efforts required should be performed prior to making this assumption.

b. Simple models and analytical solutions for the transport phenomena assessed by the performance model are necessary to interpret both field data and modeling results. While the simple solutions are not expected to duplicate the data or results, they should correlate. This provides the investigator with a means of verifying the model results.

**6.3.2 Risk Assessment Modeling.** Two different risk assessment modeling studies were conducted and it is interesting to note that the conclusions reached in each study reflect changes in the manner in which risks are currently assessed. The first study conducted in 1983 utilized the RADTRAN model developed for the NRC for use in evaluating SLD sites. It is a composite of several transport and pathways analysis models. The basic transport model is a one-dimensional unsaturated flow model and assumes a multilayered soil column. The model is very conservative since it assumes no horizontal dispersion.

The initial GCDT RADTRAN modeling showed very little migration occurring within the soil columns for either the GCD or SLD Reference cases. Given the highly arid conditions at NTS these results seemed reasonable. When the Climatic Change scenario was run, an equally small amount of migration occurred. Since this scenario involved 10 times the amount of precipitation, it was assumed that there would be an appreciable difference in radionuclide transport. Therefore parameters in the model were changed to utilize more conservative solubility and sorption coefficients. Even with these changes the results showed little migration. With each iteration, the model became more conservative and the worst case scenarios became more extreme.

It must be recognized that in 1983, the "accepted" method of performing risk modeling was to seek the upper bound of risk through worst case analyses. The NRC, through their modeling studies in the 10 CFR 61 Environmental Impact Statement, had chosen to define disposal risks through worst case scenario analyses for intrusion and groundwater transport. The investigators for the RADTRAN study were hard pressed to develop scenarios where wastes buried in GCDT would be transported in ground water. The end result was that only by inundating the GCD waste disposal zone with massive fluxes of water could it be shown that any substantial migration would occur.

The second risk assessment modeling study conducted in 1988 used a modified and improved version of RADTRAN but treated scenarios in a probablistic manner. Worst case scenarios were also analyzed but the risks were weighted in accordance with both probability and uncertainty. The differences between the 1983 and 1988 studies are notable in their approach to practices current at the time. The 1983 study attempted to define an upper bound for risk through worst case scenarios. The 1988 study bounds risk through uncertainty analysis and worst case may not result in the highest risk. Another notable difference between these studies was in the availability of information about transport mechanisms in GCDT. In 1983, investigators had little information about infiltration of precipitation events or diffusion properties of disturbed and undisturbed soils. Therefore there was the tendency to be overly conservative in assessing inundation scenarios.

The conclusions reached from these modeling studies clearly show that GCD substantially reduces the risks associated with the short- and long-term disposal of HSA wastes.

**6.3.3 Radiation Scatter Modeling.** The most successful of the modeling studies conducted was in the verification and validation of the SKYSHIN computer code for assessing doses from direct and scattered radiation during waste handling operations.

It was realized that scatter radiation during source loading, and later from the borehole, would constitute a major hazard. While there were a number of models for performing shielding calculations, there were none specifically designed to meet the GCDT shielding geometry. In order to assure that GCDT operations would not result in any unnecessary exposure, a model needed to be developed.

The initial dose assessment studies were conducted using analytical solutions for direct, skyshine, and scatter radiation. These studies were sufficiently conservative to allow preparation of radiation work plans for waste handling operations. Data from these studies were later compared with actual results and proved to be fairly accurate. These data were used in development of SKYSHIN and the model is one of the few validated radiation scatter models. SKYSHIN was later used in development of the probabilistic risk assessment for GCDT and is available for use assessing borehole operations at other facilities.

## 6.4 Evaluation of Project Goals.

The original project goals for GCDT were fully accomplished. In the area of operations, waste handling and disposal were demonstrated to be cost effective and safe. The procedures necessary to operate a GCD facility were fully developed and operations were conducted without exposure to personnel.

In field experiments, the data obtained from the tracer, tritium and monitoring studies verified that the principal transport mechanism is diffusion. The experiments provided critical information on the effectiveness of backfilling procedures and materials. Lessons learned from GCDT experiments have already been applied towards improving GCD operations and development of vadose zone monitoring systems at NTS.

As discussed earlier, validation of a total systems performance model for GCDT was not completely successful. However, the data collected and the modeling studies performed were successful in meeting project goals for assessing long-term performance of GCDT. While development of a validated performance model is still desirable, the simpler analytical models used in evaluating GCDT data have proven to be adequate in meeting the needs of current GCD operations.

## 6.5 Considerations for the Closure of GCDT.

Monitoring of GCDT will continue as part of routine environmental monitoring of the RWMS. Both temperature and tritium diffusion are approaching equilibrium. When these equilibrium points are identified and documented, instrumentation will be withdrawn and the majority of monitoring shafts will be sealed. Since some tritium is diffusing to the surface, a closure cap is recommended.

## 6.6 Considerations for Future GCD Operations and Sites.

It is apparent that the principal transport mechanism for volatile materials disposed at NTS is gaseous diffusion. The principal pathway of concern is upward migration. Disposal at depths greater that those used in routine SLD are necessary for tritium and other volatile or gas-generating wastes. While great care was taken backfilling the GCDT so as to minimize the introduction of water and it is apparent that some additional water would have aided in obtaining compaction of the backfill materials.

Much of the success in the safe and effective remote handling of wastes is attributable to the skill of RWHS equipment operators and the development and practice of procedures. While the technology used in the RWHS is readily transferable to other sites, operations managers must realize that adequate training of personnel is critical.

Obviously the combination of volatile tritium wastes with thermal wastes in the same borehole is not recommended. For GCDT these wastes were combined only for purpose of the experiments to be conducted. Sites disposing of thermal wastes must have an appropriate understanding of the heating effects on soils and surrounding wastes. Whenever possible, thermal wastes should be isolated from areas where other wastes are disposed. Simple calculations for long-term thermal distributions will allow determination of the spacing required.

There are no specific criteria for the thermal or tritium loadings of GCD boreholes but some guidelines can be derived from GCDT data. The wastes in GCDT at time of emplacement generated approximately 3,500 watts thermal. Temperature data indicate that thermal equilibrium has been reached for soils within 10-meters of the emplacement zone. Temperatures range between 30 and 40°C (approximately twice the ambient 17°C) within 10-meters horizontally and 22-meters vertically.

To clearly segregate the effects of thermal plumes from adjacent boreholes, the separation between boreholes should be such that the integrated thermal contributions should not exceed twice ambient temperatures. A "rule of thumb" that can be derived from the GCDT data is that borehole spacing should be a minimum of 1-meter per 100-watts thermal. Therefore, two boreholes, each containing 3,500-watts of thermal wastes, should be separated by a minimum of 35-meters.

Tritium data from GCDT are not truly representative of a routine GCD operation because of the presence of thermal sources. The data from GCDT does show that after four years, some tritium has diffused over 6-meters horizontally from the disposal zone. However, the diffusion/dilution effect is approximately one order of magnitude per meter. Preliminary analyses of this data indicates that a separation of 10- to 15-meters between tritium boreholes should be sufficient to distinguish diffusion plumes.

# 7.0 FINAL SUMMARY

As with all projects sponsored by the DOE's DLLWMP, technology transfer is an important goal. There were several contributions made by the GCDT project in the management of HSA wastes. These include the development of a functional and practical remote waste handling system; the development and validation of the SKYSHIN scatter radiation model; the development of tracer tests in characterizing diffusion through backfill materials; the development of isothermal diffusion models; and the principles, practices, and procedures for handling of HSA and GTCC wastes.

Perhaps the greatest successes in the GCDT project were achieved in development of operations for a borehole disposal facility. In many respects this is attributable to the fact that from the outset, GCDT was considered an operational research project to provide technology suitable for transfer to other sites. The GCDT field experiments were also successful. Data collected from these experiments were used in verifying and validating the models necessary to assess the safety and reliability of GCD operations.

The GCDT project lasted for over seven years and during that time an extensive amount of information and experience were gained. To date, ten GCD boreholes have been developed and over 100 remote waste handling operations have been conducted at NTS. The wastes disposed of in these boreholes were unsuitable for SLD or presented a significant risk to operations personnel. Without the GCDT project, it is likely that most of these wastes would have remained in storage. The true measure of success for GCDT is demonstrated by the continuing use of technology developed by the project in the management of HSA and GTCC wastes.

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# APPENDIX A

## GASEOUS DIFFUSION IN THE VADOSE ZONE: THEORETICAL BASIS FOR VOLATILE TRACER EXPERIMENTS

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## A.1 Analytical Solution of Fickian Gas Transport

Modeling the movement of tracer gas out of permeation devices and through the vadose zone involves applying Fickian gas transport theory to the specific field conditions of the STP and GCDT. By doing this, transport properties of the medium can be identified and a methodology for determining transport properties under a variety of field conditions can be developed.

Fick's second law gives the mass balance equation which described one-dimensional diffusion of one gas into another gas (Fick, 1855).

$$D\frac{\partial^2 c}{\partial x^2} = \frac{\partial c}{\partial t} \tag{1}$$

where:

D = molecular diffusion coefficient for the gas under consideration ($cm^2/sec$),
c = concentration of diffusing gas ($moles/cm^3$)
x = dimension in direction
t = time (sec).

An assumption usually implied from equation (1) is that D is constant for a given medium, temperature, and pressure but this assumption is usually only approximately and not necessarily true. As written above, the equation does not account for convection of gas or the chemical reaction of the gas, and assumes D to be constant (Jost, 1960). The above description of Fickian diffusion also assumes a constant-density, isothermal environment.

As Weeks et al. (1982) point out, the diffusion coefficient D is a constant analogous to hydraulic diffusivity (hydraulic conductivity divided by specific storage in flow through porous media) and thermal diffusivity (thermal conductivity divided by volumetric heat capacity). Therefore, the literature abounds with equations that can describe gaseous diffusion under a variety of boundary conditions (Carslaw and Jaeger, 1959; Crank, 1975).

Fick's second law can be generalized to describe gaseous diffusion into a partially saturated porous medium in one dimension as (Weeks et al. 1982):

$$\tau\theta_D D\frac{\partial^2 C}{\partial x^2} = \theta_D\frac{\partial C}{\partial t} + \rho_w\left(q_T - \theta_D\right)\frac{\partial \hat{C}}{\partial t} + \rho_s\left(1 - \theta_T\right)\frac{\partial \bar{C}}{\partial t} + \alpha \tag{2}$$

where:

$\tau$ = the tortuosity factor accounting for the added resistance to diffusion imposed by the structure of the porous medium (dimensionless),

$\theta_D$ = drained or gas-filled porosity (dimensionless),

$\theta_T$ = total porosity (dimensionless),

$\rho_w$ = density of water ($g/cm^3$),

$\rho_s$ = particle density of granular material making up solid matrix ($g/cm^3$)

$\hat{C}$ = concentration of the diffusing gas under consideration which is dissolved in soil water (mol/g of water), and

$\bar{C}$ = concentration of the diffusing gas under consideration which is sorbed on the solid matrix,

With assumptions of an immobile liquid phase that completely wets the solid phase and that rapid equilibrium occurs between the gas phase and the dissolved sorbed concentrations in the liquid and solid phases, the equation can be rewritten as (Weeks et al., 1982):

$$\tau\theta_D D\frac{\partial^2 C}{\partial x^2} = \left[q_D + \rho_w\left(q_T - \theta_D\right)K_w + \rho_s\left(1 - \theta_T\right)K_s\right]\frac{\partial C}{\partial t} + \alpha \tag{3}$$

where:

$K_w$ = liquid-gas partitioning coefficient that describes the ratio of the concentration of the gas under consideration in solution to its concentration in overlying gas phase under equilibrium conditions, (moles/gm water + moles/cm$^3$ gas),

$k_s = k_w k_d =$ gas-liquid-solid distribution product describing the ratio of the moles of the gas under consideration sorbed on the solid phase per unit mass or solid phase to the concentration of the gas in the soil atmosphere (cm$^3$ gas/gm solid), and

$k_d$ = solid-liquid distribution coefficient describing the ratio of the moles of solute under consideration sorbed on the solid phase per unit mass of solid phase to the concentration of the solute in the water (moles/gm solid per moles/gm water).

The movement of the diffusing gas of interest through the liquid film prior to sorption on the solid phase is assumed to be essentially instantaneous with respect to the overall diffusion process in this treatment.

Rearrangement of equation 3 yields:

$$\left[\frac{\tau\theta_D D}{\theta_D + \rho_w(\theta_T - \theta_D)K_w + \rho_s(1 - \theta_T)K_s}\right]\frac{\partial^2 C}{\partial x^2} = \frac{\partial C}{\partial t} + \alpha \qquad (4)$$

In this form Fick's second law is generalized to describe gaseous diffusion into a partially saturated porous medium by replacing the diffusion coefficient D with an effective (apparent) diffusion coefficient D':

$$D'\frac{\partial^2 c}{\partial x^2} = \frac{\partial c}{\partial t} \qquad (5)$$

with D' described in the non-reactive media by:

$$D' = \frac{\tau\,\theta_D\,D}{\theta_D + (\theta_T - \theta_D)\,\rho_w k_w + (1 - \theta_T)\rho_s k_s} \qquad (6)$$

D' is a "lumped" parameter which has many subcomponents and is different for each different medium and diffusing gas. Therefore, in order to gain a better understanding of the physical significance of the subparameters of the effective diffusion coefficient, individual subparameters must be determined by other means. The denominator of the right-hand side of equation 6 can be considered a sorption term, referred to as the sorption corrected porosity.

After D' is identified for a given soil and tracer, the tortuosity factor of the media, $\underline{\tau}$, can be calculated, because the other subparameters of equation 6 can be measured an/or calculated.

Equation (5) can be rewritten for 3-dimensional radial flow with spherical symmetry as (Jost, 1960):

$$D'\left[\partial^2 c/\partial r^2 + (2/r)\,\partial c/\partial r\right] = \frac{\partial c}{\partial t} \qquad (7)$$

where:

$$r = \sqrt{(x_{mp} - x_s)^2 + (y_{mp} - y_s)^2 + (z_{mp} - z_s)^2} \qquad (8)$$

mp = point of measurement, and
s = source

The medium is assumed to be homogeneous and isotropic in this form of the equation. Fick's second law for gas diffusion is analogous to equations for heat conduction in solids (Fourier's Law) and for the flow of fluids in porous media (Darcy's Law). Solutions for these equations are abundant in the literature, and there are examples with many source configurations and boundary conditions.

## A.2. Instantaneous Point Source

Carslaw and Jaeger (1959) describe a solution for temperature of any point at any time for an instantaneous point source of heat in infinite media. This 3-dimensional solution for equation (5) modified by substitution of equivalent gaseous diffusion parameters in place of heat flow parameters, is

$$C = \frac{Q}{8(pD't)^{3/2}}\,e^{-(r^2)/4D't} \qquad (9)$$

where:

Q = an instantaneously produced mass (gm) of the gas (movement and concentration of which is under observation) at a point source in an infinite medium.

## A.3 Continuous Point Source

If tracer gas is produced at a mass production rate of __(t) per unit time from t = 0 to t = 5 at the point $x_o$, $y_o$, $z_o$, the concentration at any point x, y, z at time t, by integrating (9) is:

$$C = \frac{1}{8(\pi D')^{3/2}} \int_0^t \phi(t') e^{-r^2/4D'(t-t')} \frac{dt'}{(t-t')^{3/2}} \qquad (10)$$

where:

$r^2 = (x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2$, and

t' = the variable of integration

The distribution of concentration is said to be due to a continuous point source of strength $\phi$ (t) from t = 0 onwards.

If $\phi$ (t) is constant and equal to (q), the solution for a constant point source with non-steady state diffusion is

$$C = \frac{q}{4\pi D'rA} \operatorname{erfc} \frac{r}{\sqrt{4D't}} \qquad (11)$$

where:

$$A = \theta_D + (\theta_T - \theta_D) \rho_{kw} + (1 - \theta_T) \rho_s k_s$$

As t this reduces to C = q/4D' rA which is a steady distribution of concentration in which a constant supply of tracer gas is introduced at ($x_o$, $y_o$, and $z_o$) and spreads outward into the infinite medium.

## A.4 Continuous Line Source

Adaption of the continuous line source of heat to gaseous diffusion in a porous medium gives:

where:

C = concentration in g/cc,
q = release rate in (g/sec)/length in cm,
r = radius from release line in cm,
D' = effective diffusion coefficient (g/cc),
A = sorption coefficient (unitless),
t = time in seconds,
Ei = Exponential integral.[1]

If u is allowed to equal $\frac{r^2}{4D't}$, then $D' = \frac{r^2}{4ut}$

$$A = - u \frac{Ei(-u)}{4D'C}$$

Solution of the exponential integral is:

$Ei(-u) = 0.5772 + \ln(u) - u + 1/4u^2$,

which is calculated for values of u and plotted, giving the type curve. Concentration (c) rather than Cr (in the point source solution) is plotted against $r^2/t$ for each sample station to obtain the curves used in the graphical solution. The procedure for curve matching is the same as described for the point source except that the values of C and $r^2/t$ are obtained where u = 1 and Ei(-u) = 1.

## A.5 Boundary Conditions and Image Solutions

Up until now this section has discussed general, idealized diffusion without reference to boundary conditions which can make the governing equations, which are modifications of Fick's law, applicable to actual field situations. The solutions to these partial differential equations have so far in this report represented diffusion through infinite, homogeneous, porous media.

To better describe the special case of the isothermal field test, boundary conditions can be chosen. The ground surface can be described as a zero concentration boundary for the tracer. This can be mathematically simulated by utilizing a method of images and assigning a tracer gas sink equidistant and opposite of the tracer source from the ground surface. The application of 3-dimensional method of images is schematically shown in Figure A-1. Accounting for the ground surface boundary in this way (11) can be modified to:

$$C = \frac{q}{4\pi D' r_1 A} \operatorname{erfc} \frac{r_1}{\sqrt{4D't}} - \frac{q}{4\pi D' r_2 A} \operatorname{erfc} \frac{r_2}{\sqrt{4D't}} \quad (12)$$

and (9) modified to:

$$C = \frac{Q}{8(pD't)^{3/2}} e^{-(r_1^2)4D't} - \frac{Q}{8(\pi D't)^{3/2}} e^{-(r_2^2)4D't} \quad (13)$$

$R_1$ is the radial distance at any point to the tracer's continuous point source, while R2 is the radial distance from that same point to the imaginary tracer sink as shown in Figure A-1.

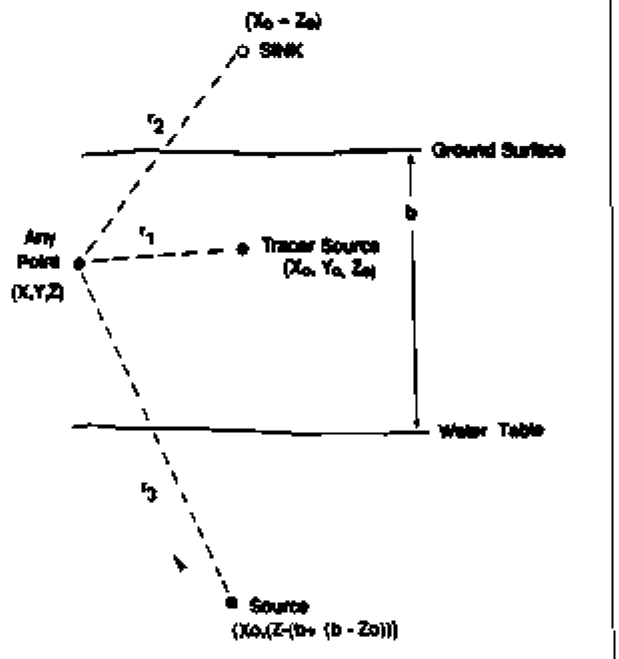

FIGURE A.1

This equation could be modified further to include a second boundary at the water table which would be assigned as a zero flux boundary because: 1) low solubility of tracer gases in water (BCD and SF6 tracers are only slightly soluble in hot or cold water), 2) slow vertical flow of water at the water table and capillary fringe, 3) compounded by the situation of relatively short field test duration. This added condition would be treated again by method of images with tracer source, opposite of equidistant from the water table.

When using a method of images where parallel images are employed, a series of images is reflected to infinity. Figure A-2 illustrates this effect. This series is mathematically written with each additional sink or source subtracted or added respectively from or to the right side of equation (12) in the same fashion as the hypothetical sink added to equation (11) to represent a zero concentration boundary at the ground surface. the only mathematical difference between these reflections of reflections is that each has a different location.

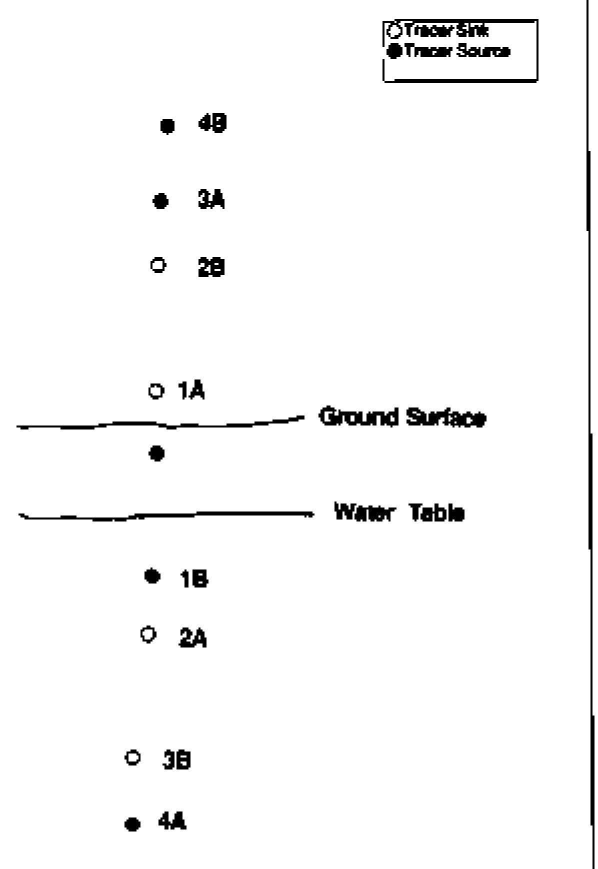

FIGURE A.2

The mathematical description of tracer tests use only the first sink image, and assume that the ground surface is the boundary of most importance to analytical solutions of transient diffusion processes. The justification for excluding other images is that for the short time period of the field experiment, only the closest image will have even a slight effect on the final solution. Also, by neglecting all but the first image the mathematical treatment is briefer, and more manageable.

Any analytical solution for gaseous diffusion experiments utilize equation 12 for continuous, point source tracer tests, and equation 13 for instantaneous point source tracer tests.

The holes, drilled for the GCDT and STP, were backfilled with an alluvial material which is different (finer) than the surrounding alluvium. The sides of the holes therefore represent a material boundary where hydraulic, diffusive, or thermal properties of the porous media have the possibility of varying abruptly. The tracer experiment data help ascertain if a difference in diffusivity exists between the two media, and if differences exist within either one separately. Unless otherwise indicated, the porous, vadose zone material are considered homogenous and isotropic for any analytical solution of gaseous diffusion tests.

## A.6 Least Squares Analysis for Obtaining Diffusion Parameters

In order to estimate the effective diffusion coefficient D', a least squares approach can be employed. This method finds a D', which will minimize the squares of the difference between measured field concentration of tracer (Ci*) at any radial distance and time, and the computed concentration of tracer (Ci) at those same ri and ti, where i is a counter that indicates the number of concentration measurements. The function to be minimized in this case if F(D') where

$$F(D') = \sum_{i=1}^{N} \left[ C_i^* - C_i \right]^2 \tag{14}$$

where:

N = the total number of measurements

Minimizing programs can be used to solve equation (14) by reducing square of the sum of differences between observed and computed values. Use of these computer programs usually involves an initial guess for the variables D' (effective diffusion coefficient), and in the case of the continuous point source, A, (a sorption term). Through iterative means the program optimize D' (and A) to achieve the least sum of the square of the differences between observed and calculated concentrations. Care must be exercised not to mistakenly find local minimums to the function described by Equation (14).

## A.7 Graphical Superposition Techniques for Obtaining Diffusion Parameters

Application of curve matching techniques to gaseous diffusion tracer tests is unsaturated porous media allows data to be easily interpreted. The technique, developed for application to <u>in situ</u> gaseous diffusion testing by Kreamer (1982), is analogous to the Theis method for analysis of drawdown data from aquifer tests and allows the quick determination of the effective diffusion coefficient without the use of a computer. In this technique, each data point is given equal weight, unlike the least squares approach where larger values of concentration are emphasized.

For example, equation 11 (in the continuous point source case with no material boundaries) can be modified by multiplying both sides by the radial distance r and by substituting the square root of the argument of the complementary error function. Equation (11) can then be written:

$$rC = \frac{q}{4\pi D'A} \operatorname{erfc} \sqrt{u} \tag{15}$$

$$u = \frac{r^2}{4D't} \tag{16}$$

To prepare a type curve of equation 11, arbitrary values of erfc _u vs u are plotted on logarithmic (log-log) paper. Next, the observed values of rC vs. $r^2/t$ are plotted on log-log paper of the same scale. Holding the coordinate axes of the two curves parallel, the curves are matched so that the observed data best fit the type curve. A common point (match point) is arbitrarily chosen anywhere on the overlapping portion of the sheets, providing the user with mutual values of rC, erfc $\sqrt{u}$, r2/t and u, which may be inserted into equations (15) and (16). The equations can then be solved for D' and A. Once values of D' and A are calculated, they can be checked, as analogously suggested by Davis and DeWiest, (1966), by computing 4D' and q/4 π D'A. These values must correspond to r2/t and rC respectively for u = 1 and erfc $\sqrt{u}$ = 1. This matching technique is illustrated in Figure A.3. Further information on curve matching techniques can be found in Ferris et al. (1962).

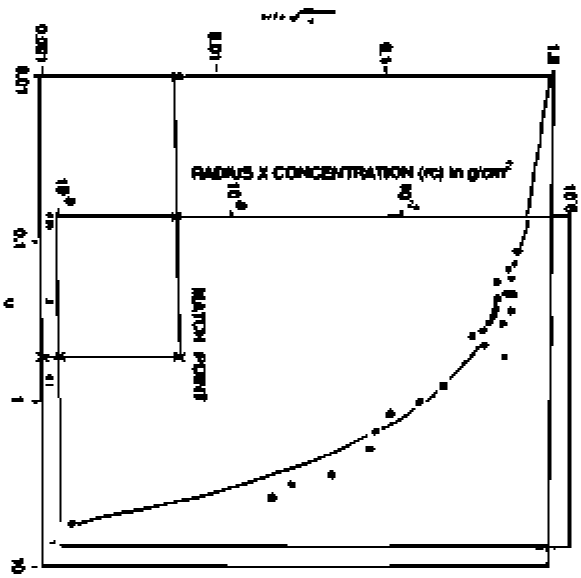

FIGURE A.3