The Department of Energy HAZMAT Spill Center Data Base

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1. INTRODUCTION

During the late 1970's when energy prices were escalating, a primary energy resource was the importation of liquefied natural gas (LNG) from the Middle East using cryogenic transport vessels. A concern was the consequence of an accidental release of LNG during the off-loading from a transport to on-shore storage facilities. Minimal information was available regarding the behavior of such a release and efforts were undertaken by the United States Department of Energy (DOE) to develop mathematical models based on large-scale controlled releases of LNG under different conditions to understand the dynamics of such an event. To conduct large-scale experiments of such a potentially lethal substance as LNG required access to a relatively isolated location with adequate control to exclude non-essential personnel.

The first two LNG experiments series performed by Lawrence Livermore National Laboratory (LLNL) under contract to the DOE were conducted at the Naval Weapons Center (NWC), China Lake, California. After completion of these two field studies it was decided to build a permanent facility where capabilities could be constructed allowing larger releases with better control. The U.S. Congress funded the construction of such a facility called the Liquefied Gaseous Fuels Spill Test Facility (LGFSTF) to be located on Frenchman Flat (a dry lakebed) on the Nevada Test Site (NTS). By the time the facility was commissioned and ready for use by research groups, it was decided that more than just liquefied gaseous fuels needed to be investigated. There was a need for a research facility that could allow the release of various hazardous chemicals under controlled conditions without endangering the public. The LGFSTF was tasked by DOE to meet this need, and its name was changed to reflect this new task. It is now called the Hazmat Spill Center (HSC).

Being located on the NTS has some unique advantages that fit requirements of the type of research performed at the HSC. Since most of the U.S. nuclear weapons tests were conducted at the NTS, the location of the NTS was made for many of the same reasons required for hazardous materials release studies. These are summarized below:

- It is remote and isolated from any nearby population centers. The nearest metropolitan area is Las Vegas, NV, located about 65 miles to the southeast of the NTS. The nearest neighbor downwind from the NTS is the Nellis Air Force Range, which is also restricted to public access. This allows release of large volumes of toxic materials with adequate downwind areas for dispersion of these materials long before contact with public accessible areas.
- The access to the NTS is restricted because of the type of research projects performed on site and their relationship to national security. This precludes unauthorized personnel from approaching the release locations or accessing the downwind areas where concentrations may be dangerous to personnel.
- The presence of minimal vegetation or wildlife reduces potential environmental harm. While there is some vegetation and wildlife, the DOE maintains strict regulations on what can be released and has filed Environmental Impact Statements (EIS) assessing the consequences of the release of those materials for which the site has currently been permitted.
- Prior to the previous nuclear testing analysis was made of the meteorology for the area. This was critical in selection of the site originally and continued collection of atmospheric data has allowed prediction of specific meteorological conditions that are hard to capture on any other site on a reliable basis. This is particular important when designing instrument arrays to capture dispersion clouds or specific atmospheric conditions.

When the HSC was completed in 1987, the construction provided for three large liquid storage tanks, each 98+ m^3 (26,000+ gallons) in capacity. Two of these were insulated to allow storage of cryogenic materials, i.e., LNG, and were connected to other high-pressure tanks where N_2 was stored to allow pressurized discharge of the cryogenic liquid at high rates. The discharge was usually via one of two 12" diameter release lines that extended from the tank locations to the spill location about 500' away. All of the control and measurement of this system was remotely monitored by the Command and Control Data Acquisition System (CCDAS) located in a control room about 1 km upwind from the tank farm. The CCDAS also allowed for additional instruments and sensors to record data as required for the specific experiment being conducted.

The type of studies performed at HSC has varied over the years. The following describes some of the different studies performed at the HSC over the years:

- Dispersion studies of large volume releases of chemicals.
- Source characterization or understanding how a material behaves when released from its normal storage container or a pressurized reactor.
- Evaluation of mitigation techniques, i.e., mechanical vapor barriers, spray nozzles to knock down plumes, foam vapor barriers.
- Evaluation of protective clothing when exposed to toxic and/or corrosive materials in a wind tunnel.

2. HAZMAT SPILL CENTER CAPABILITIES & FACILITIES

The HAZMAT Spill Center, located at the Department of Energy's Nevada Test Site near Mercury, Nevada, is a unique, one-of-a-kind facility built to conduct hazardous materials testing and training under controlled conditions. The HSC, 75 miles northwest of Las Vegas, can accommodate both large- and small-scale testing. The HSC Environmental Impact Statement allows live releases of hazardous materials for training purposes, field-test detection, plume dispersion experimentation, and equipment and materials testing. Tests are conducted from April through September, weather permitting.

This unique facility is available for private and public sector sponsors on a user fee basis to cover actual test costs plus clean-up costs to prepare the facility for other customers. With the HSC's unique release permits and spill rates up to 28,000 gallons per minute and spill volumes expandable to 75,000 gallons, the HAZMAT Spill Center is capable of the following:

"Live" HAZMAT Testing

Applications:

- Test protective gear
- Test HAZMAT instrumentation
- Test equipment and procedures

Advanced HAZMAT Training

Applications:

- Train the trainers or leaders
- HAZMAT specialists
- Gain confidence in equipment and procedures by using live material
- First responder (state, municipal and industrial)

Mitigation Technology

Applications:

- Test mitigation techniques using live material
- Test and validate computer mitigation models
- Conduct research for new techniques

Remote Sensing

Applications:

- Effluent analysis
- Stand-off HAZMAT identification

Source Term Definition - Dispersion Modeling

Applications:

- Computer model testing and validation
- Development of new computer models for HAZMAT dispersion

The HAZMAT Spill Center's facilities include:

- **Wind Tunnel** (8 ft x16 ft x 96ft) - an environmental test chamber, allows mixing and mitigation technology research as well as plume releases
- **Elevated Stacks and Spill Pads** - available for realistic industrial release scenarios
- **Test Cell Areas** - allows materials and instrumentation to be exposed to known, high concentrations of test materials in a confined space

- **Tank Farm** - contains systems for the release of large volumes of liquids, gases and cryogenic liquids
- **Command, Control and Data Acquisition Systems** - controls and records data from tests using monitoring and sensor stations
- **Other Support Facilities**:
    - Electronics Shops
    - Maintenance Shops
    - Conference Facilities
    - Storage Buildings
    - Chemical Storage Areas

3. THE U.S. DOE'S HAZMAT SPILL CENTER DATABASE

In 1986, Congress passed the Superfund Amendment and Reauthorization Act (SARA), and Section 118(n) specified that funding should be made available to conduct technology transfer of the DOE LGFSTF Research Program. Western Research Institute (WRI) of Laramie, WY, became the repository for the database developed from these experiments conducted at the HSC. The database is available via the Internet on WRI's WEB site located at: http://www.westernresearch.org/Projects/STFDB/DataPage.htm.

The data collected from these different experiments were primarily developed with public funds or provided by private companies or consortiums representing more than one industrial concern.

The data in these files are a combination of raw data and others that have been processed through reduction, calibration and verification procedures from which an individual can begin their own analysis. To understand the organization of the data, its origin or location within a specific experiment, or its reliability, the user is directed to the references provided at the end of each section describing a series of tests.

4. DATABASE ORGANIZATION

To date the data have been placed on the WEB site in two separate batches. The first batch contained the data from experiments conducted after 1988. These data were made available in the mid 1990s and were converted from simple text files to comma separated values (CSV files) to simplify importation into data analysis and plotting applications. The second batch was comprised of the early dispersion experiments conducted at China Lake and the LGFSTF prior to 1988. These experiments contain a great deal of raw data and their organization is slightly different than the later experiments. The data files from both batches contain time stamped records for the various sensors used in the experiments. The time stamps for the pre-1988 data are provided in seconds with "0 seconds" being the start of the release of material. The time stamps for the pre-1988 data are provided in time of the day format (24 hour format) and the user must determine when the release started from and compute an elapsed time from the start of the release.

The pre-1988 files

The pre-1988 data has not been converted into CSV files from the original text files. WRI has processed the files to help the user identify the different tower and sensor locations within a data set. Because the naming convention and organization of the data within these early experiments was not always consistent, WRI has added at the top of each separate data file 2-4 lines of text to identify where the sensors are located and what the individual columns of data represent. These added lines of text are surrounded by quotes with the character string "<WRI>" appended to the end of each new text line. These files can be opened either by a word processing application or imported into a spreadsheet or plotting application. Other than the extra lines of text added by WRI and some of the original header information provided by LLNL, the data is in a fixed width format.

The pre-1988 data is typically divided into four types of data:

1. Concentration data from sensors placed downwind from the source,
2. Heat flow data measurements of heat flowing from the surface into the dispersing cloud,
3. Relative humidity from various locations in the test grid, and
4. Temperature measurements made upwind and downwind from the source as the plume was dispersing.

These four categories of data are organized into separate subdirectories and contain individual data files with naming conventions that vary between test series. In addition to those four categories of data contained in the individual subdirectories, there are normally four additional files that are stored in the root directory of the specific test. These files are typically:

1. A test identification files that summarizes the experiment,
2. A table that displays the location of all the various sensors used in the experiment and their locations on a tower,
3. A tower location file that provides the coordinates of the individual towers used in the experiment, and
4. A wind data file that provides measurements of wind speed and direction from a number of sensors in the test grid.

A test series is provided as a single executable file. When executed the data files and subdirectories are self-extracted from a zipped format into their text file format.

The post-1988 files

The second batch of files (the post-1988 data files) is slightly different than the pre-1988 tests but is consistent with how they are organized. The WEB site is organized with a test series per page, each test data page contains one executable file for each test in the test series as well as a file named DOC.EXE that contains information documenting the test series. These executable files are actually self-extracting zip files that, when executed, create one or more comma separated value (CSV) text files containing the actual test data or other test information.

Each TESTxx.EXE file contains one to three CSV text files, TESTxx.CSV, TESTxxW.CSV, and TESTxxG.CSV, where xx is the test number. The first file, that with no W or G suffix, is the data collected by the data acquisition system in the control room at the STF; all of the tests on the site include this file. The second file, that with a W ("W" is for wind) suffix, is wind speed and direction data collected by 2-m meteorological towers during the tests. The final file, that with a G ("G" is for gas) suffix, is only applicable to the Silicone Health Council (SHC) test series and contains gas concentration information. Each of these files is structured in a similar fashion. The values in the first row are the 'tag names' for each data channel. After the first row, each row in a file is a record of the input values at the time denoted by the timestamp located in the first column. A "????????" indicates that the data acquisition system did not record a valid value for that sensor at that time.

Each DOC.EXE file contains one or two text files, test.DBB, where 'test' is the test series abbreviation, and TAGNAMES.TXT. The test.DBB file is a copy of the database used to control the data acquisition system during a test and has some information useful in understanding the sensors associated with the tag names. Where possible, a TAGNAMES.TXT file has been included that more fully describes the sensors associated with tag names, as well as other relevant test information.

The organization of this report

Currently the DOE HSC database contains all experiments except the data from the Kit Fox Series conducted in 1995. Discussion of all database files in the WRI archive is provided, even though they may not currently be available on the WRI WEB site. There are currently 13 different test series that are included in the DOE HSC database although other experiments have been conducted at the HSC. The other experiments were not funded or conducted as investigations of hazardous materials behavior but were performed at the HSC because of its unique location and capabilities.

Because of the number of different experiments conducted and the resulting databases available, only an overview or quick summary of the different experiments can be provided in this report. The following information is provided for each of the experiments included in the DOE HSC database. It should be noted that beginning with the earliest experiments, a tradition (which has not always been followed) was established by LLNL of naming a test series with an animal name related to the NTS or the desert environment, these were done alphabetically beginning with the name Burro for the first LNG series conducted at China Lake, CA.

- Test Name
- Sponsor
- Dates of experiments
- Chemicals released
- Brief description of experiments
- List of public domain references for Data Reports or analyses

5. BURRO SERIES

Sponsors: U.S. Department of Energy and Gas Research Institute (GRI)

Dates of Experiments: June 6 – September 17, 1980

Chemical released: Liquefied Natural Gas Releases (LNG)

Description of experiments: During the summer of 1980, a series of LNG spill experiments were performed at the Naval Weapons Center, China Lake, CA. The experiments involved eight (8) LNG spills and one liquid nitrogen release (which is not included in the database files), each approximately 40 m^3, onto a water surface. The release point was in the center of a small pond ~58-m in diameter, 1-m deep and its surface was ~1.5-m below the surrounding ground level. This was to simulate the accidental release of LNG during an off-loading scenario in an aquatic environment where LNG would be spilled onto a water surface. Personnel from NWC and LLNL performed these experiments jointly.

The release point was instrumented to measure the instantaneous rate of LNG discharge from the 25-cm diameter insulated release line. Release rates varied from ~10 m^3/min to ~16 m^3/min. Downwind instrumentation was organized into arrays at different distances up to 800m downwind from the spill point and located on towers to accommodate multiple levels of sensor measurements. Data acquisition provided for sensor capture before, during, and after cloud passage. Sensors were provided for determining meteorological measurements including wind speed, wind direction, humidity, and temperature. These were positioned both upwind and downwind from the release point. At five stations (towers), bi-vane anemometers were installed to measure atmospheric turbulence within the test grid, but these data were not provided by LLNL to WRI for the DOE HSC database (plots of some of this data are provided in the Burro Data Report [Koopman, et al., 1982a]).

Heat flux sensors to measure heat flow between the ground and the dispersing cloud were located on the desert surface at locations in the downwind arrays. Type K thermocouples were positioned on the downwind array towers to measure cloud temperature as it moved downwind. Open path IR sensors for the measurement of LNG concentration were positioned at multiple levels on the downwind arrays. High-speed motion-picture cameras and infrared imagers were also positioned to make visual recordings of the experiments.

Predominate wind direction at the China Lake site is from the southwest or 225^o. The upwind and downwind sensor arrays were located around a test grid centerline corresponding to the 225^o azimuth. The individual towers on each downwind array were then spaced out from either side of the centerline at distances from 13-m to 80-m as the downwind distance increased. Figure 1, provides a drawing of the test grid as depicted in the Burro Data Report (Koopman, et al., 1982a). Table 1 provides a summary of the Burro Test Series in the DOE HSC database.

Table 1 – Summary of Burro Series

	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Released material	LNG	LNG	LNG	LNG	LNG	LNG	LNG	LNG
Date	6/18/80	7/2/80	7/9/80	7/16/80	8/5/80	8/27/80	9/3/80	9/17/80
Time of day for start of spill (PDT)	15:59:28	15:00:06	14:07:27	16:19:36	16:05:06	18:12:21	19:09:22	18:37:08
Duration (sec)	173	166	175	190	128.5	174	107	79
Spill Rate (m^3/min)	11.9	12.2	12.1	11.3	12.8	13.6	16.0	18.4
Spill Volume (m^3)	34.3	34.0	35.3	35.8	27.5	39.4	28.4	24.2
Avg. Wind Dir. (^{o} from true north)	221	224	217.5	218	220	208.4	234	232
Avg. Wind Speed (m/sec)	5.4	5.4	9.0	7.4	9.1	8.4	1.8	5.7
Surface Roughness - z_o (m)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Monin-Obukhov length (m)	-11.3	-9.06	-37.1	-25.5	-45.0	-114.0	16.5	-140.0

List of Further Reading for Burro Series

Ermak, D.L., S.T. Chan, D.L. Morgan, and L.K. Morris, 1982, “Comparison of Dense Gas Dispersion Model Simulations with Burro Series LNG Spill Test Results”, Journal of Hazardous Materials, Vol. 6, pp.129-160.

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Koopman, R.P., R.T. Cederwall, D.L. Ermak, H.C. Goldwire Jr., W.J. Hogan, J.W. McClure, T.G. McRae, D.L. Morgan, H.C. Rodean, and J.H. Shinn, 1982, “Analysis of Burro Series 40-m^3 LNG Spill Experiments”, Journal of Hazardous Materials, Vol. 6, pp. 43-83.

Morgan, D.L. Jr., 1988, “Dispersion Phenomenology of LNG Vapor in the Burro and Coyote LNG Spill Experiments”, Journal of Heat Transfer, Vol. 109.

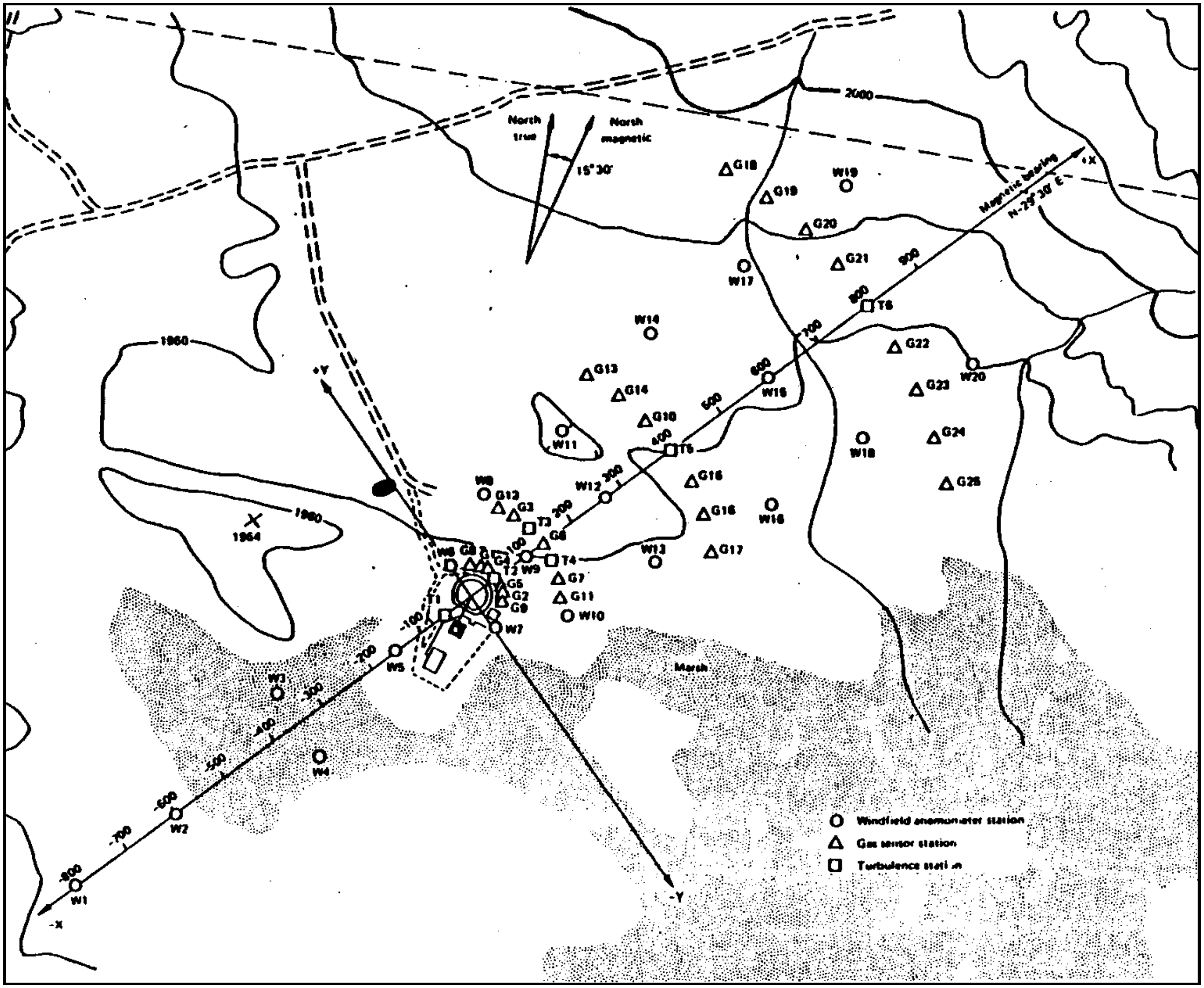

Figure 1 - Burro Series Test Grid (Koopman, et al., 1982a)

6. COYOTE SERIES

Sponsors: U.S. Department of Energy and Gas Research Institute (GRI)

Dates of Experiments: June 30 – November 24, 1981

Chemical released: Liquefied Natural Gas Releases (LNG)

Description of experiments: The Coyote Series of LNG spill experiments was performed at the Naval Weapons Center, China Lake, CA, during the summer and fall of 1981. Personnel from NWC and LLNL performed these experiments jointly. There were ten (10) Coyote experiments, five primarily for the study of vapor dispersion and burning vapor clouds, and five for investigating the occurrence of rapid-phase-transition (RPT) explosions. When data was transferred from LLNL to WRI, only data for three Coyote experiments was provided, Tests 3, 5 and 6. Most of the experiments released LNG, two used liquefied methane and one used liquid nitrogen. The three tests where data is available are described as vapor burn experiments where the cloud was ignited after the release. The releases were conducted on a water surface using the same small pond and release configuration as in the Burro Series.

As in the Burro Series, the release point was instrumented to measure the instantaneous rate of LNG discharge from the 25-cm diameter insulated release line. Release rates varied from ~6 m^3/min to ~19 m^3/min, with total volumes spilled from ~3 m^3 to 28 m^3. Downwind instrumentation was organized into arrays at different distances of 110 up to 500-m downwind from the spill point and located on towers to accommodate multiple levels of sensor measurements. Sensor measurements were acquired before, during, and after cloud passage. Wind field measurements were made using two-axis cup-and-vane anemometers located at 20 stations and positioned 2-m above the ground. These were positioned both upwind and downwind from the release point. Humidity sensors were located upwind and at multiple downwind locations from the spill point.

Bi-vane anemometers were installed to measure atmospheric turbulence at heights of 1.36, 3, and 8-m at two locations (62-m upwind of the spill point and 300-m downwind of the spill point). These data were not provided by LLNL to WRI for the DOE HSC.

Heat flux sensors to measure heat flow between the ground and the dispersing cloud were located on the desert surface at locations in the downwind arrays. Type K thermocouples were positioned on the downwind array towers to measure cloud temperature as it moved downwind. Just upwind of the spill point not only were multiple levels of thermocouples but also four resistive temperature devices (RTD), one defined as the absolute temperature (0.5-m height) and three to provide delta temperature measurements relative to the absolute reading (1, 2, and 4-m).

Because of the experience gained in the Burro Series experiments, the downwind gas concentration sensor arrays were modified. This was based on the facts that beyond 400-m from the spill point the very low concentrations made the sensors of limited value, and water and mud thrown up by RPT explosions had adverse effects on sensors close to the spill point. Most of the open-path IR sensors for the measurement of LNG concentration were positioned at multiple levels on the downwind arrays between 140 and 400-m. In addition, some alternate sensors from International Sensor Technology and Mine Safety Appliance for measuring concentration were installed.

Because of the objective to observe vapor cloud fires during some of the releases, sensors were installed to measure flame velocity during these vapor cloud fires, two devices were installed. Four calorimeters manufactured by Hy-Cal Engineering were installed at four downwind stations at a height of 1-m. Twenty-seven (27) LLNL developed flame-velocity sensors were deployed at nine towers downwind of the spill point at three different levels.

Five high-speed 16-mm motion-picture color cameras and side-on IR imaging video recorders were also positioned to make visual recordings of the experiments. Nine radiometers were deployed by the NWC personnel for the purpose of measuring both the radiative heat flux at several distances from the vapor cloud fires and the emissive power of the fire.

The individual towers on each downwind array were then spaced out from either side of the centerline, Figure 2, provides a drawing of the test grid as depicted in the Coyote Data Report (Goldwire, et al., 1983). Table 2 provides a summary of the Coyote Test Series in the DOE HSC database.

Table 2 – Summary of Coyote Series

	Test 3	**Test 5**	**Test 6**
Released material	LNG	LNG	LNG
Date	9/3/81	10/7/81	10/27/81
Time of day for start of spill	15:38:26 PDT	12:08:50 PDT	16:43:23 PST
Duration (sec)	65	98	82
Spill Rate (m^3/min)	13.5	17.1	16.6
Spill Volume (m^3)	14.6	28.0	22.8
Avg. Wind Dir. (^{o} from true north)	205	229	220
Avg. Wind Speed (m/sec)	6.0	9.7	4.6
Surface Roughness - z_o (m)	0.0002	0.0002	0.0002
Monin-Obukhov length (m)	-6.32	-26.5	73.6

List of Further Reading for Coyote Series

Goldwire, H.C., Jr., H.C. Rodean, R.T. Cederwall, E.J. Kansa, R.P. Koopman, J.W. McClure, T.G. McRae, L.K. Morris, L. Kamppinen, R.D. Kiefer, P.A. Urtiew, and C.D. Lind, 1983 "Coyote Series Data Report, LLNL/NWC 1981 LNG Spill Tests, Dispersion, Vapor Burn, and Rapid-Phase-Transition", Lawrence Livermore National Laboratory, CA, UCID-19953 Vol.1 and Vol.2.

Koopman, R.P., "Coyote Series for 40-m^3 Liquefied Natural Gas (LNG) Dispersion, RPT, and Vapor Burn Tests", 1982, Lawrence Livermore National Laboratory, CA, UCID-19211-Rev.1.

Morgan, D.L. Jr., 1988, "Dispersion Phenomenology of LNG Vapor in the Burro and Coyote LNG Spill Experiments," Journal of Heat Transfer, Vol. 109.

Rodean, H.C., W.J. Hogan, P.A. Urtiew, H.C. Goldwire, Jr., T.G.McRae, and D.L. Morgan, Jr., 1984, "Vapor Burn Analysis for the Coyote Series LNG Spill Experiments," Lawrence Livermore National Laboratory, CA, DOE Report UCRL-53530.

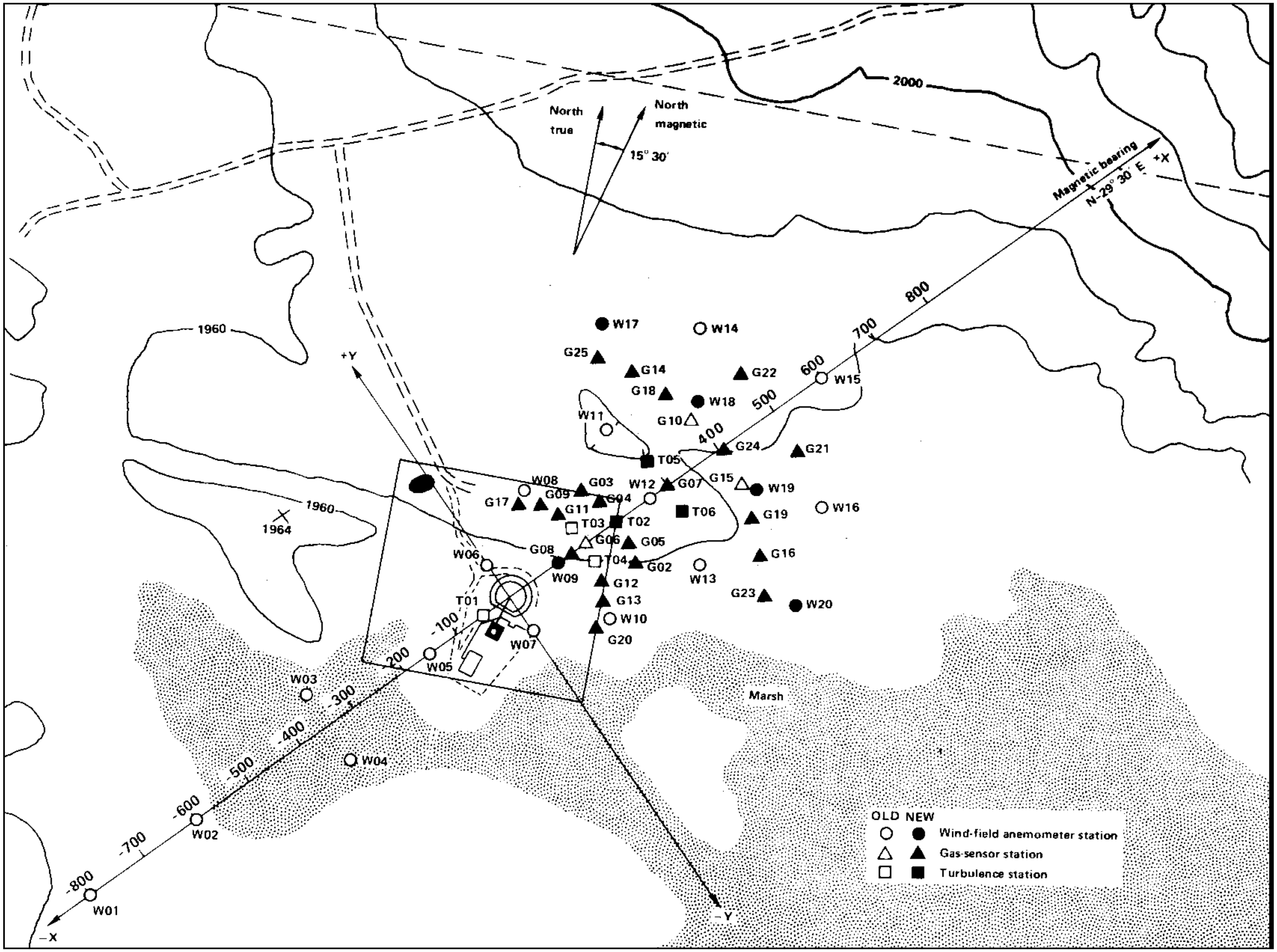

Figure 2 - Coyote Series Test Grid (Goldwire, et al., 1983)

7. DESERT TORTOISE SERIES

Sponsors: U.S. Coast Guard and The Fertilizer Institute

Dates of Experiments: August 24 – September 6, 1983

Chemical released: Anhydrous Ammonia (NH_3)

Description of experiments: The Desert Tortoise Series of ammonia spill experiments was performed by LLNL at the Frenchman Flat area of the Nevada Test Site during the summer of 1983. There were four (4) experiments for the study of atmospheric dispersion of the spilled material under various meteorological conditions. The size, shape, and temperature of the ammonia clouds, as well as the extent of the hazardous concentrations downwind were to be determined. In order to simulate simple cases that later could be modeled, the tests were performed at constant pressure and on the dry lakebed which provided a relatively flat and smooth surface.

The release point was instrumented to measure the instantaneous rate of ammonia discharge from the 6-inch diameter release line. The spill region was instrumented with three thermocouples placed at the soil surface at distances downwind along the centerline at 3, 5, and 9-m from the spill point. These were to provide a measure of soil temperature prior to a test and information on ammonia pooling. A Hy-Cal Engineering heat flux gauge was placed just below the soil surface at 3-m downwind of the spill point.

Wind field measurements were made using two-axis cup-and-vane anemometers located at 11 stations and positioned 2-m above the ground. These were positioned both upwind and downwind from the release point. 50-m upwind of the spill point were four levels of 1000 Ω platinum RTD mounted in aspirated solar shields. Bi-vane anemometers were installed to measure atmospheric turbulence at three heights at two locations (50-m upwind of the spill point and 100-m downwind of the spill point). The bi-vane data were not provided by LLNL to WRI for the DOE HSC database but are provided as plots in the Desert Tortoise Data Report (Goldwire, et al., 1985).

The downwind instrumentation grid of multiple levels of sensors was defined by two arrays, a mass flux array at 100-m and dispersion array at 800-m downwind from the spill point. Up to eight additional portable ground-level stations were fielded in two distant arcs at distances of 1,400 or 2,800-m and on occasion, at 5,500-m downwind.

Heat flux sensors to measure heat flow between the ground and the dispersing cloud were located on the desert surface at multiple locations in the downwind arrays. Type K thermocouples were positioned on the downwind array towers at multiple heights to measure cloud temperature as it moved downwind.

The primary sensors used to determine ammonia concentration on the 100-m mass flux array were MSA non-dispersive IR (NDIR) gas sensors. International Sensor Technology solid-state gas sensors were the primary means to determine gas concentration on the 800-m dispersion array. The open-path IR sensors developed by LLNL for the measurement of LNG concentration in the Burro and Coyote Series were sensitive to ammonia absorption when no water fog was present and were positioned at several locations on the downwind arrays at 100 and 800-m.

Photographic and video recordings of the experiments were provided with 16-mm movie cameras, programmable framing cameras, and black and white video coverage.

Table 3 – Summary of Desert Tortoise Series

	Test 1	Test 2	Test 3	Test4
Released material	Ammonia	Ammonia	Ammonia	Ammonia
Date	8/24/83	8/29/83	9/1/83	9/6/83
Time of day for start of spill (PDT)	16:37:47	11:20:56	15:37:47	18:15:07
Duration (sec)	126	255	166	381
Spill Rate (m^3/min)	7.0	10.3	11.7	9.5
Spill Volume (m^3)	14.9	43.8	32.4	60.3
Avg. Wind Direction (^{o} from true north)	223.66	226.21	219.07	229.30
Avg. Wind Speed @ 2m (m/sec)	7.42	5.76	7.38	4.51
Surface Roughness - z_o (m)	0.003	0.003	0.003	0.003
Monin-Obukhov length (m)	92.7	94.7	570.7	45.2

List of Further Reading for Desert Tortoise Series

Goldwire, H.C., Jr., T.G. McRae, G.W. Johnson, D.L. Hipple, R.P. Koopman, , J.W. McClure, L.K. Morris, and R.T. Cederwall, 1985, "Desert Tortoise Series Data Report, 1983 Pressurized Ammonia Spills," Lawrence Livermore National Laboratory, CA, UCID-20562.

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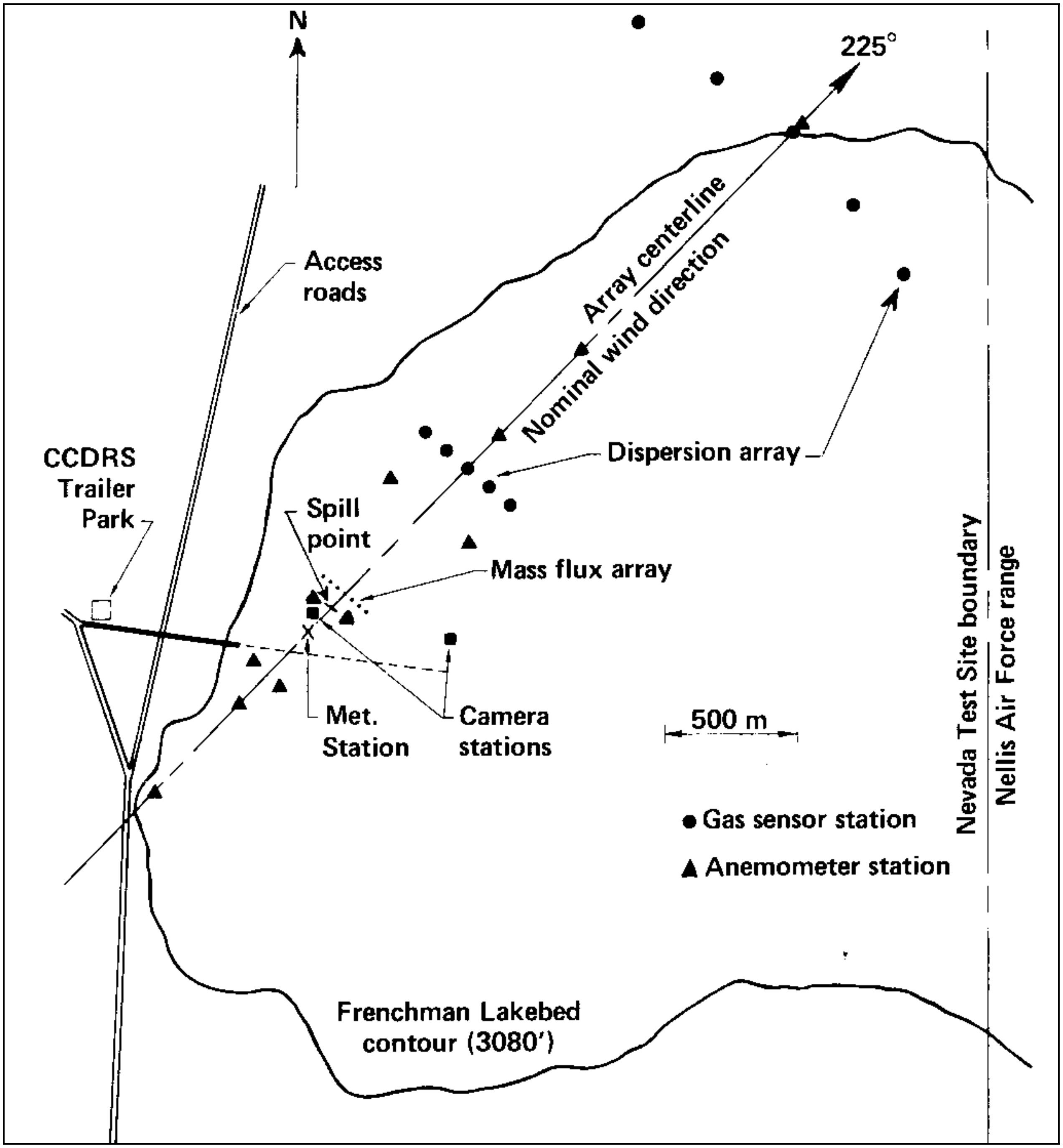

Figure 3 – Desert Tortoise Series Test Grid (Goldwire, et al., 1985)

8. EAGLE SERIES

Sponsor: U.S. Air Force

Dates of Experiments: September 17 - October 30, 1983

Chemical released: Nitrogen Tetroxide (N_2O_4)

Description of experiments: The Eagle Series of nitrogen tetroxide (N_2O_4) spill experiments was performed by LLNL at the Frenchman Flat area of the Nevada Test Site during the fall of 1983. There were six (6) experiments to determine the heavy gas dispersion aspects and source strength characteristics of large N_2O_4 spills. In addition, they were to provide N_2O_4 spills for the evaluation of a Portable Foam Vapor Suppression System (PFVSS). The dispersion and source strength experiments were under the sponsorship and direction of Engineering and Services Center, Tyndall AFB. The Ogden Air Logistics Center, Hill AFB with support from the USAF Space Division and the Strategic Air Command directed the PFVSS efforts. Tests 1, 2, 3, and 6 were for the purpose of dispersion and source strength studies and these are the data provided by LLNL to WRI that are part of the DOE HSC database. Test 4 and 5 were for the evaluation of the PFVSS and are not included in the DOE HSC database.

Two different spill configurations were used during the experiments, a single exit release and a multi-exit release. The single-exit, confined spill configuration was for studying evaporation rates as a function of liquid pool depth and wind speed. The multi-exit unconfined configuration was designed to distribute N_2O_4 uniformly over a large area to allow it to evaporate rapidly. The single point release was used for Test 1 (which was primarily a check-out and determine source strength) and the PFVSS evaluation conducted during Tests 4 and 5, see Figure 4. Real-time measurement of release rate was provided with a flow meter during Test 1 but even though the unit was advertised to be acid-proof it was destroyed by the N_2O_4 and wasn't available for subsequent tests. The amount of N_2O_4 released was determined by measuring the pressure difference between the headspace and the bottom of the tanker vessel. Based on release duration and total volume released, an average flow rate was reported.

The temperature of the N_2O_4 just prior to its exit from the spill pipe was recorded. Three Hy-Cal Engineering heat flux gauge were placed just below the surface of the soil near the spill point. Adjacent to the spill point three thermocouples (Type K) placed at three different heights (ground level and 2 and 4 cm) were used to measure vapor temperature during the dispersion and source characterization tests (Tests 1, 2, 3, and 6). During these tests the N_2O_4 was spilled directly onto the desert surface. During the PFVSS evaluation tests the N_2O_4 was spilled into a polyethylene plastic liner to help confine the liquid, see Figure 4. The spills directly onto the lakebed playa surface exhibited considerable outgassing from the surface for several hours after the spill was terminated.

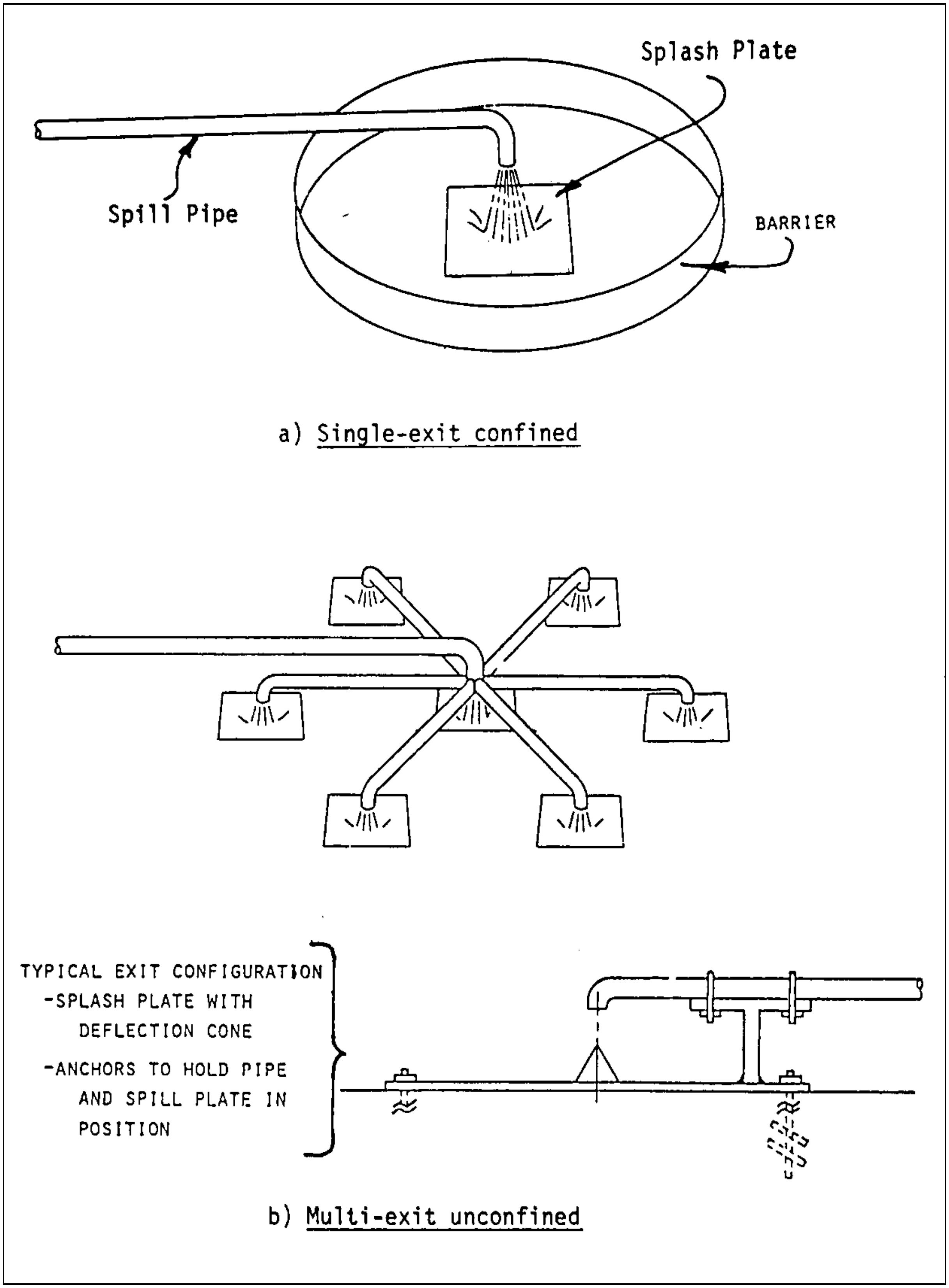

Figure 4 – Eagle Series Release Configurations (McRae, et al., 1987)

Wind field measurements were made with nine stations using two-axis cup-and-vane anemometers positioned 2-m above the ground. These were positioned both upwind and downwind from the release point. Meteorological boundary layer measurements were made on a 20 m tower located 50 m upwind of the spill point. This tower was installed with four levels of 1000 Ω platinum RTD mounted in aspirated solar shield at heights of 0.82, 2.46, 6.13 and 16.2 m. In addition there were three Gill bi-vane anemometers installed at 3.36, 5.83 and 12.1 m. to measure atmospheric turbulence. A Hy-Cal Engineering heat-flux gauge was installed at ground level. Additional meteorological measurements were made on a 10 m tower located 25 m downwind on the centerline of the test grid. This tower had three Gill bi-vane anemometers at 1.3, 3.0 and 6.0 m plus three temperature measurements (Type K thermocouples). The bi-vane data were not provided by LLNL to WRI for the DOE HSC database but some of the data are provided as plots in the Eagle Series Data Report (McRae, et al., 1987).

The downwind instrumentation grid of multiple levels of sensors was defined by two arrays, a mass flux array at 25 m and dispersion array at 785 m downwind from the spill point, see Figure 5. Two additional portable NO_2 ground level stations were fielded at distances 2,800 m downwind, the data from these sensors was not provided to WRI by LLNL.

In addition to the heat flux sensors located on the meteorological tower up wind of the spill point and near the spill point two were located on the mass flux array 25 m downwind from the spill point. These were to measure heat flow between the ground and the dispersing cloud. Type K thermocouples were positioned on the downwind mass flux and dispersion array towers at multiple heights to measure cloud temperature as it moved downwind.

The primary sensors used to determine N_2O_4 and NO_2 concentration on the 25 m mass flux array were the open-path IR sensors developed by LLNL for the measurement of LNG concentration in the Burro and Coyote Series. They were capable of measuring both species without any modifications. The 785 m dispersion array was instrumented with NO_2 sensors manufactured by Energetic Sciences, Inc. and provided by the Shuttle Activation Task Force, Vandenburg AFB. Two additional NO_2 sensors manufactured by International Sensor Technology were also used on this dispersion array but were greatly affected by small variations in relative humidity and were not reported in the Eagle Data Report or in the data set provide by LLNL to WRI. The two portable sensors NO_2 sensors were Interscan Model 140D electro-chemical transducers providing an analog signal recorded on a strip chart recorder. These data were not provided to WRI by LLNL for the DOE HSC database.

Photographic and video recordings of the experiments were provided with 16-mm movie cameras, programmable framing cameras, and black and white video coverage. There was only video coverage of the Eagle 6 test.

Table 4 – Summary of Eagle Series

	Test 1	Test 2	Test 3	Test6
Released material	Nitrogen Tetroxide	Nitrogen Tetroxide	Nitrogen Tetroxide	Nitrogen Tetroxide
Date	9/17/83	9/23/83	10/7/83	10/30/83
Time of day for start of spill	14:07 PDT	17:02 PDT	16:48 PDT	14:37 PST
Spill configuration	Multi-exit	Multi-exit	Multi-exit	Multi-exit
Duration (sec)	45	65	188	296
Average Spill Rate (m^3/min)	1.75	1.4	1.4	0.7
Spill Volume (m^3)	1.3	1.5	4.2	3.4
Avg. Wind Direction (^{o} from true north)	233	223	229	223
Avg. Wind Speed @ 2m (m/sec)	6.15	5.80	3.13	4.96
Surface Roughness - z_o (m)	0.0003	0.0003	0.0003	0.0003
Monin-Obukhov length (m)	-20.2	-198.0	16.8	293.0

List of Further Reading for Eagle Series

Koopman, R.P., T.G. McRae, H.C. Goldwire Jr., D.L. Ermak, and S.T. Chan, 1985, "Results of Recent 1983 NH_3 and N_2O_4 Spill Tests," Proc. - Inst. Environ. Sci., Vol. 31.

Koopman, R.P., D.L. Ermak, and S.T. Chan, 1988, "Review of Recent Work in Atmospheric Dispersion of Large Spills," Lawrence Livermore National Laboratory, CA, UCRL-97377.

McRae, T.G., R.T. Cederwall, D.L. Ermak, H.C. Goldwire, D.L. Hipple, G.W. Johnson, R.P. Koopman, J.W. McClure, and L.K. Morris, 1987, "Eagle Series Data Report: 1983 Nitrogen Tetroxide Spills," Lawrence Livermore National Laboratory, CA, UCID-20063, Rev.1.

McRae, T.G., 1985, "Analysis and Model/Data Comparisons of Large-Scale Releases of Nitrogen Tetroxide. Final Report June 1983 - September 1984," Lawrence Livermore National Laboratory, CA, UCID-20388.

McRae, T.G., 1985, "Evaluation of Source Strength and Dispersion Model Predictions withData from Large Nitrogen Tetroxide Field Experiments," Lawrence Livermore National Laboratory, CA, UCRL-91402.

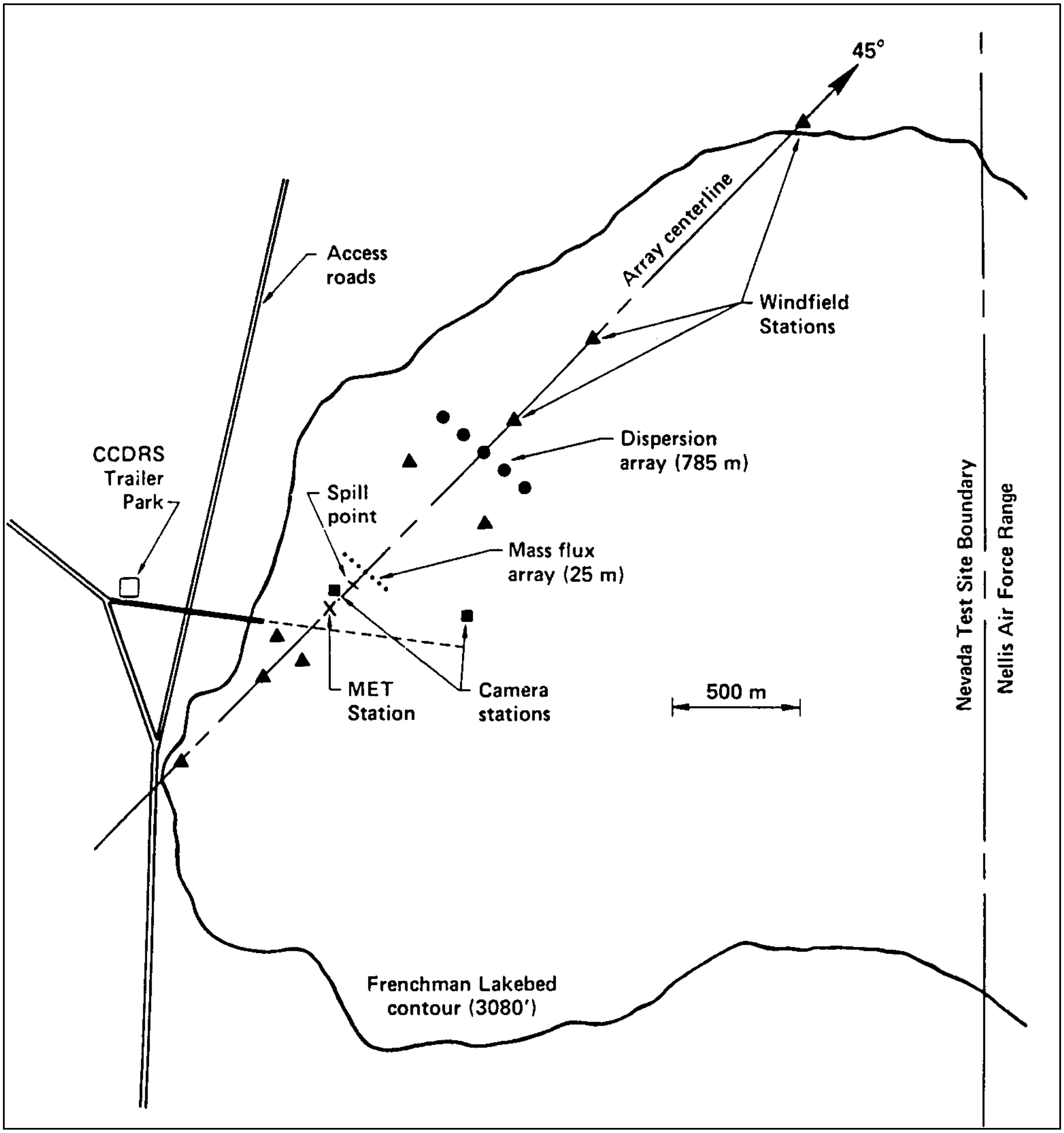

Figure 5 – Eagle Series Grid (McRae, et al., 1987)

9. FALCON SERIES

Sponsors: U.S. Department of Transportation and Gas Research Institute (GRI)

Dates of Experiments: June 12 – August 29, 1987

Chemical released: Liquefied Natural Gas (LNG)

Description of experiments: The Falcon Series of liquefied natural gas (LNG) spill experiments was performed by LLNL at the Frenchman Flat area of the Nevada Test Site during the summer of 1987. These were the first tests performed at DOE's permanent Spill Test Facility. A series of five (5) spills were performed on water within a vapor barrier structure as part of a joint government/industry study. These experiments were performed to evaluate the effectiveness of vapor fences as a mitigation technique for accidental releases of LNG. They also provided a database for the validation of wind tunnel and computer modeling simulations of vapor fence effects on LNG dispersion. Spills were made onto a water pond equipped with a circulation system to maximize evaporation to make the source evaporation rate as nearly equal to the spill rate a possible.

These experiments used the new Spill Test Facility tank farm that contained two 26,000 gallon cryogenic storage tanks that were connected to the spill point with a 500 ft long spill pipes which were comprised on two 12 inch insulated lines and one 6 inch insulated line (which was not used in these experiments). Each spill pipe was equipped with a control valve at each end.

Prior to a LNG release, the spill line(s) were cooled with liquid nitrogen after which the LNG was delivered to the spill line by operating valves controlled remotely from the control room located approximately a mile form the release area, see Figure 6. The LNG was pressure driven out of the storage tanks and through the spill pipes by means of nitrogen drive gas at 35 to 140 psig. The drive gas was supplied from a 2,000 psig, 2,400 ft^3 pressure vessel.

To provide uniform LNG distribution on the pond, a multi-exit release configuration was built. Each of the four arms of the multi-exit was approximately 11.6 m in length, was oriented 90^o from adjacent arms, and was fitted with a restrictive orifice near the end to prevent flashing in the release pipe. The pond was 40 x 60 m and was filled to a depth of approximately 76 cm, see Figure 7. Located upwind from the pond was a large "billboard" structure 17.1 m wide and 13.3 m high to simulate the turbulence created by a typical storage tank. The "billboard" was made of a proprietary fiberglass cloth impregnated with a mixture of silicon, Teflon, and graphite and reinforced with aluminum battens and suspended from 13.7 m aluminum pillars. Around the pond and simulated storage tank was installed a vapor fence structure fabricated from the same material used in the "billboard" and suspended from 9.1 m aluminum pillars with stainless steel cables. As shown in Figure 8, the vapor fence was 44 m wide and 88 m long and was 8.7 m high.

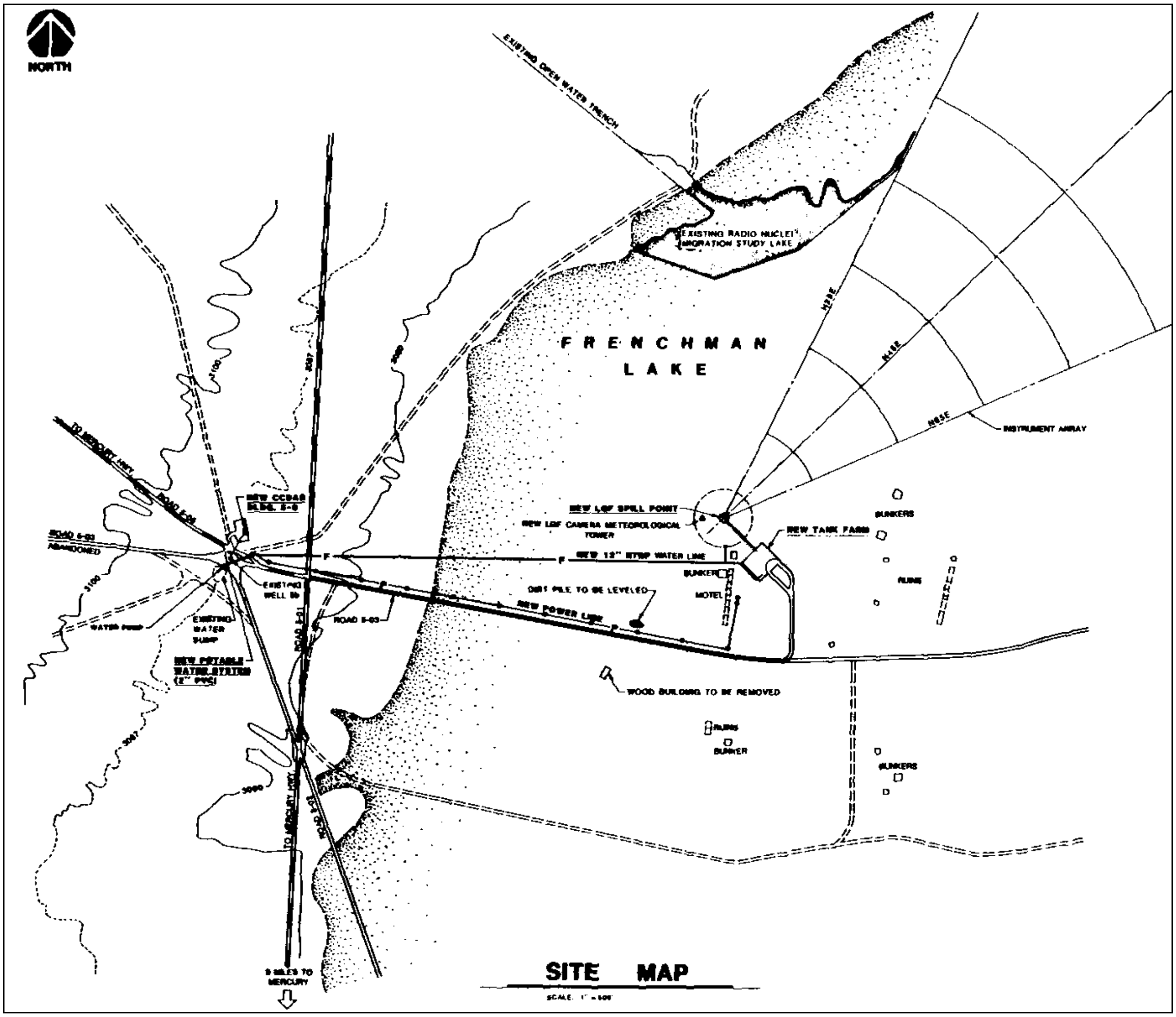

Figure 6 – U.S. DOE Spill Test Facility Layout (Brown, et al., 1990)

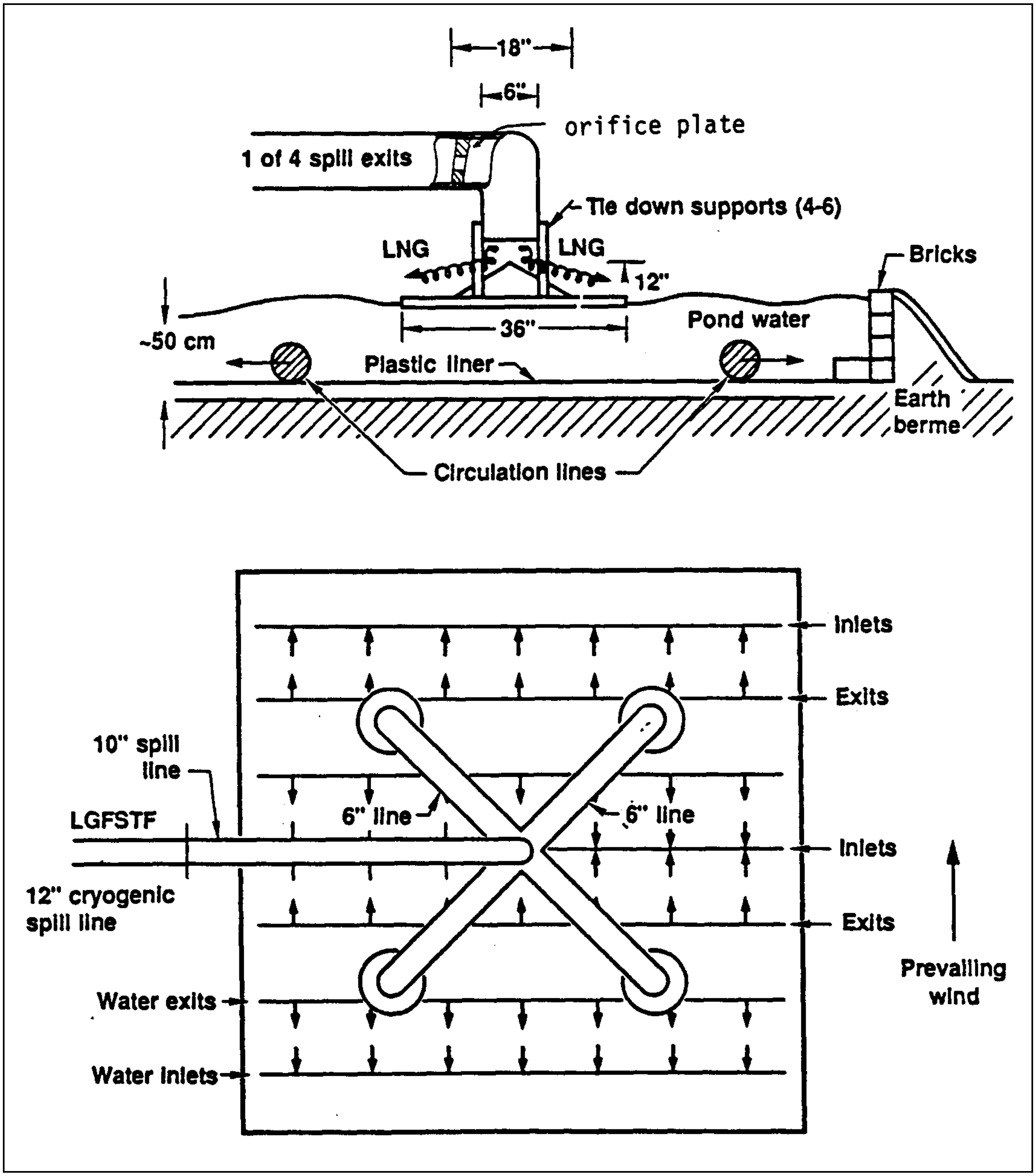

Figure 7 – Falcon Series Multi-exit Release Configuration (Brown, et al., 1990)

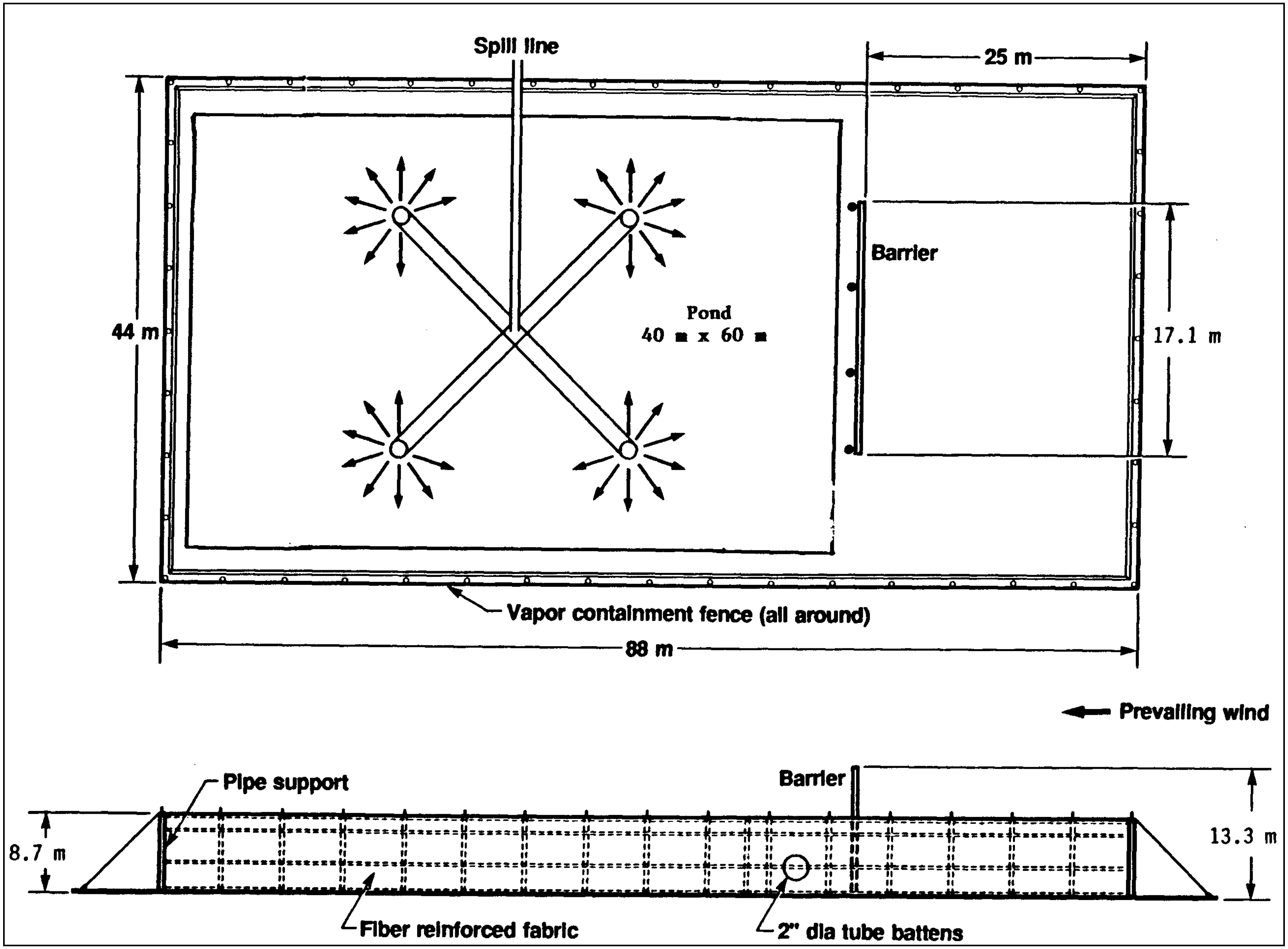

Figure 8 – Falcon Series Pond and Vapor Barrier Fence (Brown, et al., 1990)

The spill area was instrumented with numerous Type K thermocouples to record temperatures at various locations within the vapor barrier fence. These were within the pond and upwind of the "billboard". Heat flux sensors were also placed within the vapor barrier fence area as well as at three four locations downwind of the spill area outside of the vapor barrier fence. Humidity sensors were located both within and outside the vapor barrier fence. The spill line from the tank farm to the spill area was instrumented to provide instantaneous measurement of the flow rate of LNG to the spill area.

Wind field measurements were made with 19 stations using two-axis cup-and-vane anemometers (Met-One) positioned 2-m above the ground. These were positioned both upwind and downwind from the release point. Meteorological boundary layer measurements were made on a 20 m tower located 130 m upwind of the spill point and 25 m off the centerline of the test grid. This tower was installed with five levels of 1000 Ω platinum RTD mounted in aspirated solar shield at heights of 1, 2, 4, 8 and 16 m. In addition there were three Gill bi-vane anemometers installed at 1, 4 and 16 m to measure atmospheric turbulence. An additional 15 bi-vane anemometers were installed at heights of 1, 5 and 11 m on 5 towers located downwind of the spill point. The bi-vane data were not provided by LLNL to WRI for the DOE HSC database but some of the data are provided as plots in the Falcon Data Report (Brown, et al., 1990).

The downwind instrumentation grid of multiple levels of sensors was defined by three arrays, at 50, 150 and 250 m from the downwind end of the vapor barrier fence. On these downwind array towers Type K thermocouples were positioned at multiple levels, 4 heights on the 50 and 150 m arrays and 3 heights on the 250 m array, to measure cloud temperature as it moved downwind. The exception to this was the tower located on the centerline of the 150 m array which had four levels of RTD sensors rather than thermocouples. Between Tests 3 and 4, two towers and their associated instrumentation were moved from the 50 m array and added to the 150 m array to increase the width of the 150 m array, see Figures 9 and 10. This was done based on the wider than anticipated clouds created during the first three experiments.

A total of seventy-seven (77) gas concentration sensors were deployed during the experiments. There were four (4) IR sensors developed by the Jet Propulsion Laboratory for use during the Burro and Coyote tests that measured concentration within the vapor barrier fence area. Thirty-five (35) of the LLNL-IR sensors developed for the Burro Series were deployed at the lowest heights on the 50 and 150 m downwind arrays. Thirty-eight (38) MSA catalytic sensors were located at higher heights at the 50 and 150 m arrays and at the 250 m arrays where gas concentration were not anticipated to exceed 5%.

Photographic and video recordings of the experiments were provided with 16-mm movie 24 frame/second cameras, programmable framing cameras, and color video coverage.

Table 5 - Summary of Falcon Series

	Test 1	Test 2	Test 3	Test 4	Test 5
Released material	LNG	LNG	LNG	LNG	LNG
Date	6/12/87	6/18/87	6/29/87	8/21/87	8/29/87
Time of day for start of spill (PDT)	19:47:56	18:09:09	18:52:02	19:27:04	18:58:00
Duration (sec)	131	78	154	301	78
Spill Rate (m^3/min)	28.7	15.9	18.9	8.7	30.3
Spill Volume (m^3)	66.4	20.6	50.7	44.9	43.9
Avg. Wind Direction (^{o} from true north)	234.3	227.0	221.7	230.6	218.0
Avg. Wind Speed @ 2m (m/sec)	1.7	4.7	4.1	5.2	2.8
Surface Roughness - z_o (m)	0.008	0.008	0.008	0.008	0.008
Monin-Obukhov length (m)	4.963	-103.4	-442.2	69.38	13.69

List of Further Reading for Falcon Series

Brown, T.C., R.T. Cederwall, D.L. Ermak, R.P. Koopman, J.W. McClure, and L.K. Morris, 1990, “Falcon Series Data Report, 1987 LNG Vapor Barrier Verification Field Trails,” Gas Research Institute, 8600 West Bryn Mawr Avenue, Chicago, IL 60631, GRI-89/0138.

10. GOLDFISH SERIES

Sponsor: Amoco Corporation

Dates of Experiments: August 1986

Chemical released: Anhydrous Hydrofluoric Acid (HF)

Description of experiments: During the summer of 1986, Amoco Oil Company and LLNL conducted the Goldfish Series of anhydrous hydrofluoric acid (HF) spill experiments at the Frenchman Flat area of the Nevada Test Site. The objectives of the six experiments were threefold. First, to obtain basic information regarding the source characteristics during an atmospheric release of HF stored at an elevated pressure and temperature. Secondly, to provide downwind concentration measurements of HF in both the dense gas and toxic gas regions for comparison against the performance of denser gas dispersion models. Lastly, the final three tests were designed to provide information on the effectiveness of water spray systems for reducing the downwind concentration of HF. The data for the last three tests (4, 5 & 6) were not transferred to WRI from LLNL for the DOE HSC database.

The spill release configuration was designed to release HF as a horizontal jet. The HF spill equipment consisted of the following primary elements: (1) spill tank connected to the discharge line, (2) liquid HF collection pad, (3) liquid HF collection pipe, and (4) vapor vent pipe, see Figure 9. The spill tank was a 5,000-gallon trailer connected to a 4-inch diameter spill line. The tank was fitted with electric hating so the liquid HF could be maintained at approximately 40^{o}C. A load cell was positioned under one end of the tank to provide a continuous record of the weight of the trailer and all calculation of the rate at which HF was released. A high-pressure gaseous nitrogen tube trailer provided dry nitrogen to pressurize the HF spill tank. The end of the release line was equipped with a remote controlled spill valve that was used to start and stop the spill. An orifice plate located at the end of the release line controlled the flow rate.

A collection pad to collect and drain into the liquid collection system any HF that was not entrained into the atmosphere was constructed at the end of the release line. The pad was approximately 9 m wide and 61 m long and was constructed of 80 mil UV stabilized polyethylene. During each release the amount of HF released was measured by recording the HF tank weight, the orifice temperature and pressure, the HF temperature, and the drive gas pressure.

During Tests 3, 4, 5 & 6, additional atmospheric water vapor was provided to study the effects of increased relative humidity on the resulting cloud. This was attempted using two different methods. First, a steam boiler and water injection system was located upwind of the spill point. The injection system consisted of an array of spray nozzles, half for steam and half for warm water and were located approximately 25 m upwind of the release point. The length of the spray system was 22 m and the system was located approximately 3 m above the ground.

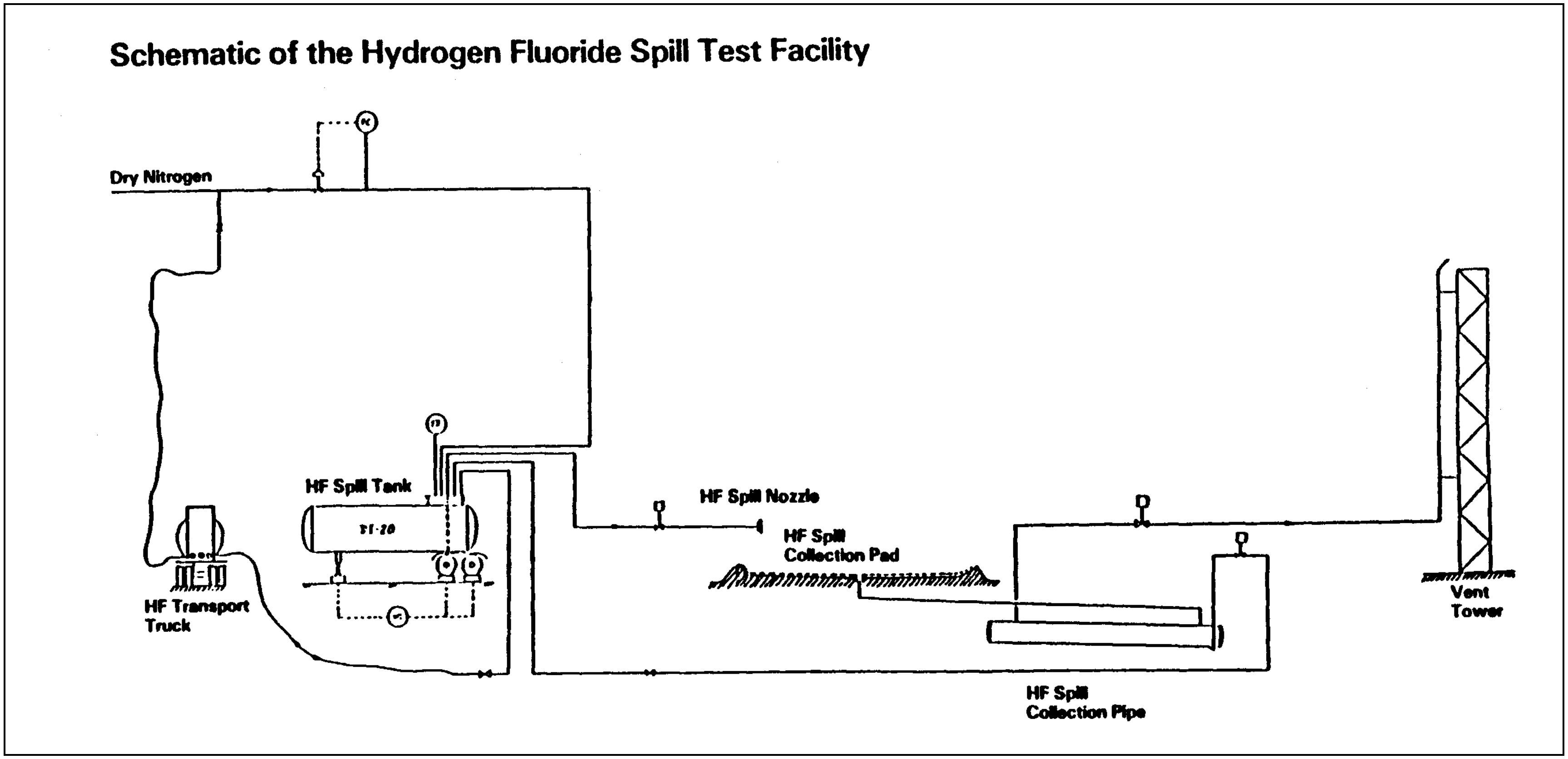

Figure 9 – Configuration of the Goldfish Series Experimental Components (Blewitt, et al., 1987a)

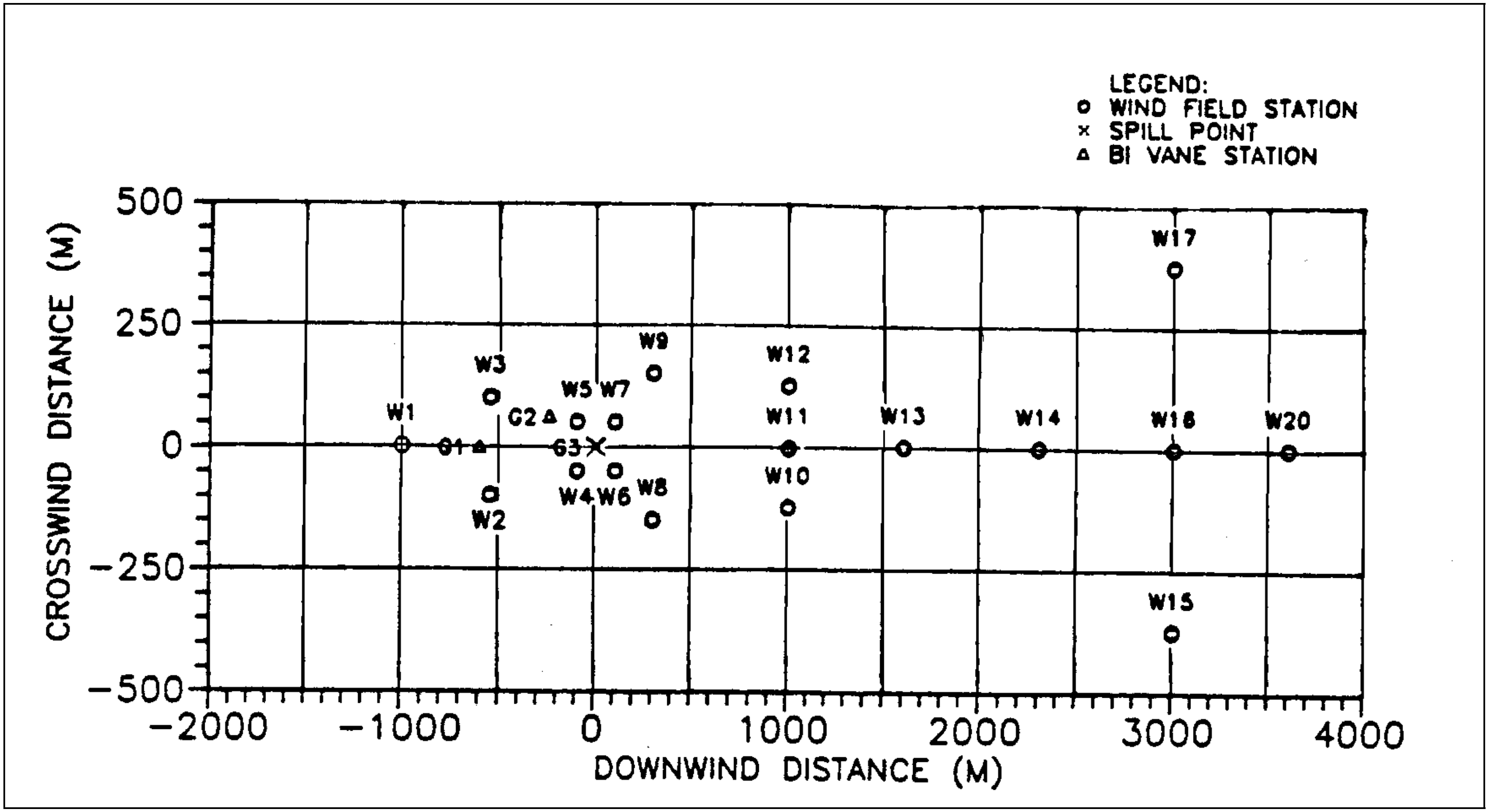

Figure 10 – Goldfish Series Wind Field Instrumentation (Blewitt, et al., 1987a)

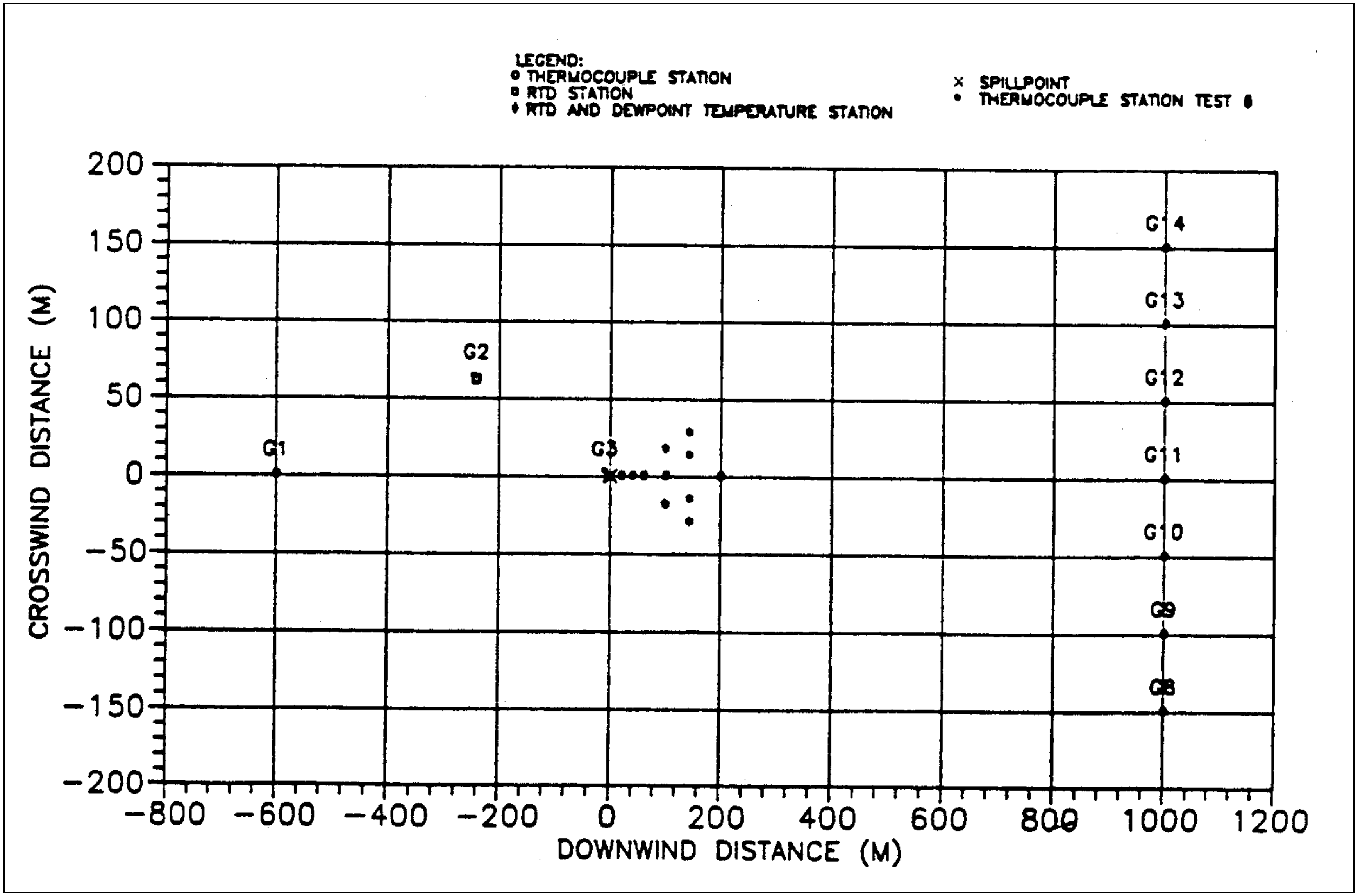

Figure 11 – Goldfish Series Temperature Sensors (Blewitt, et al., 1987a)

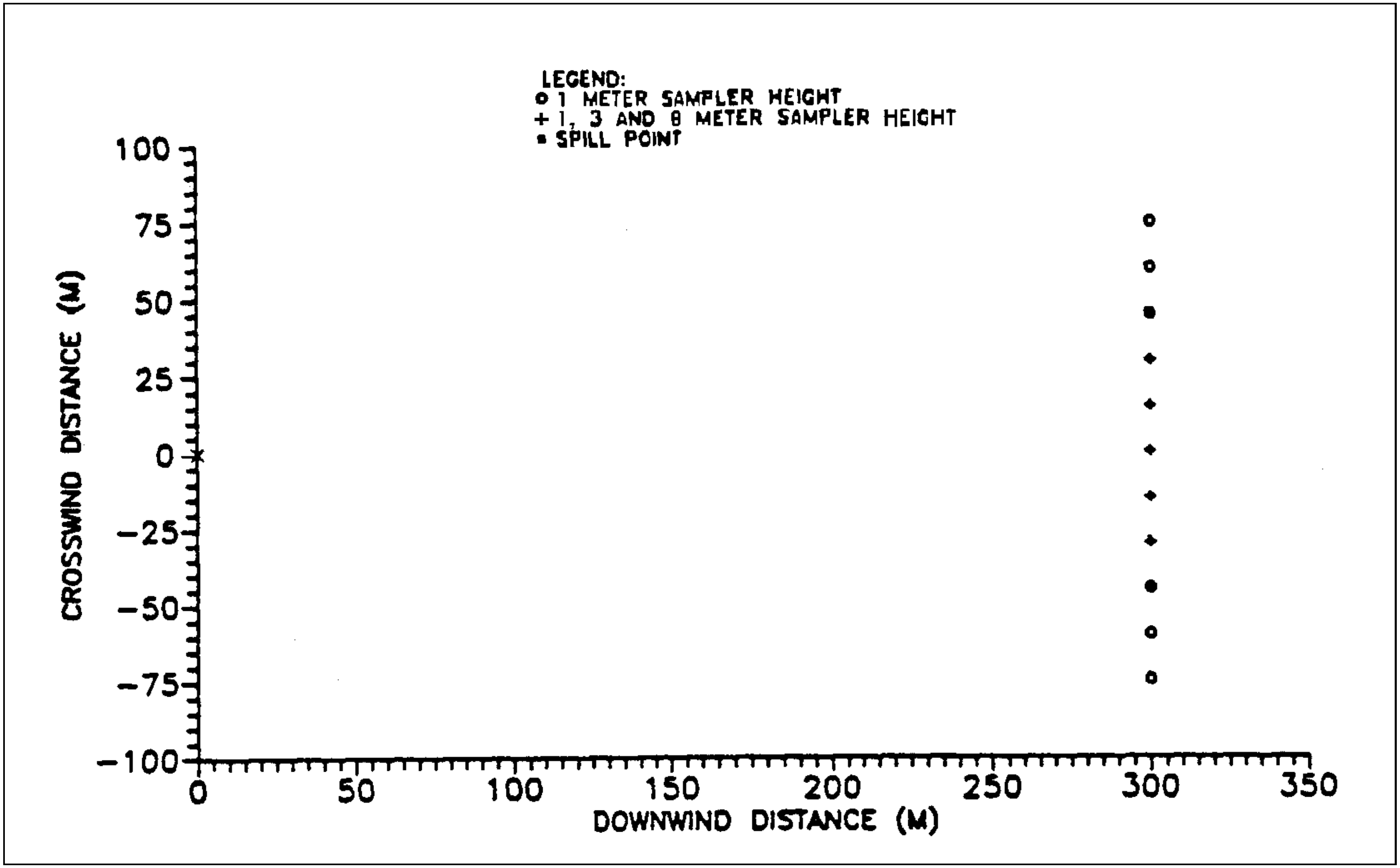

Figure 12 – Goldfish Series Concentration Sensors at 300 m (Blewitt, et al., 1987a)

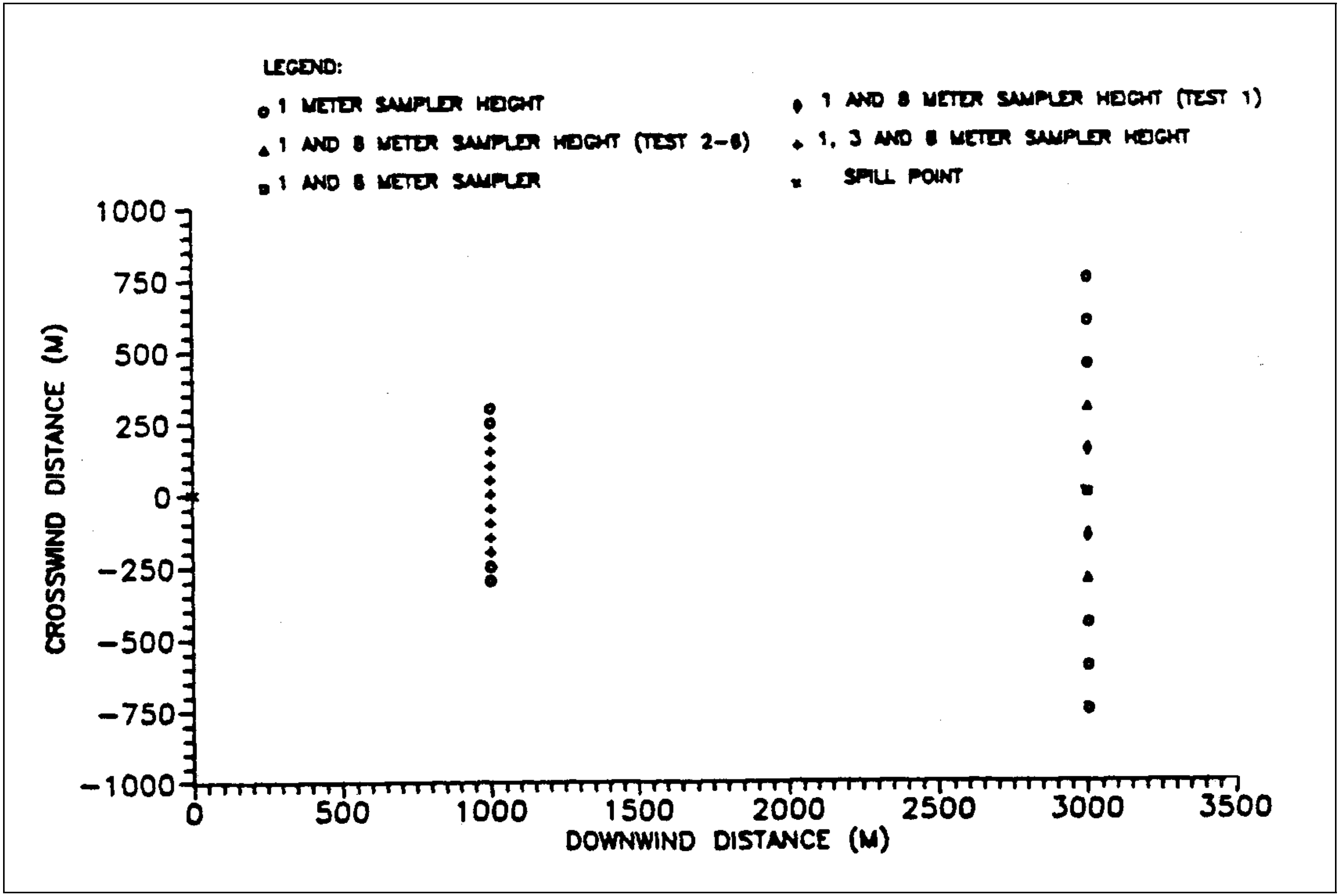

Figure 13 – Goldfish Series Concentration Sensors at 1,000 and 3,000 m (Blewitt, et al., 1987a)

The nozzles were oriented horizontally and pointed upwind from the spill point. The second technique involved a shallow pond, 250 m by 600 m, which was constructed upwind of the spill point.

Vertical wind profile and turbulence were measured using three Gill bi-vane anemometers installed at a tower 600 m upwind of the release point. The data from these sensors were not transferred from LLNL to WRI for the DOE HSC database. On this same tower, five (5) levels of platinum RTD sensors at heights of 1, 2, 4, 8 and 16 m were installed to measure the ambient temperature and temperature lapse rate. Eighteen (18) stations using two-axis cup-and-vane anemometers (Met-One) positioned 2-m above the ground were used to determine the characteristics of the wind field before, during and after each release (Figure 10).

Temperature measurements were made with Type J thermocouples housed in naturally aspirated radiation shields. These were used to primarily measure cloud temperature during a release, see Figure 11.

Concentration measurements of HF downwind of the spill point were made at three arrays located 300, 1,000 and 3,000 m downwind from the spill point. The centerline of the array was aligned with the 225^o azimuth that corresponded with the predominate wind direction at the Frenchman Flat site. The sensors on the 300 m array were located at heights of 1, 3 and 8 m on the centerline of the array and at ±15 and ±30 m from the centerline, see Figure 12. Additional sensors were located at 1 m heights at ±45 and ±60 m from the centerline. After Test 1, two additional sensors were located at ±75 m from the centerline. At the 1,000 m array the sensors were located at heights of 1 ,3 and 8 m at the centerline, ±50, ±100, and ±150 m from the centerline. For Test 1, sensors were located at 1 m for the ±200 and ±250 m, with additional sensors at 1 m for ±300 m for test 2 through 6. For the 3,000 array sensors were located at height of 1, 3 and 8 m at the centerline of the array and at ±150 m, see Figure 13. Additional sensors were located at the 1 m height at ±300, ±450, ±600 and ±750 m for Test 1. After test 1, the ±300 m location was augmented with sensors at 3 and 8 m heights.

Two types of sensors were utilized in the downwind arrays. The first was an Integrated Filter sampler (IF) developed by Amoco and the second was the GMD HF analyzer. The IF data is reported in the HSC database but the GMD HF analyzer data was not reported either in the references (Blewitt, et al., 1987a, 1987b, and 1987c) nor provided in the data transferred from LLNL to WRI for the DOE HSC database. The IF sampler consisted of 10 Gelman filter cassettes which were treated with a sodium formate solution and were loaded into a sampling manifold for each release. A sampling manifold had 10 solenoid valves which opened in sequence to expose each cassette to an ambient air sample. The sampling time for each filter varied from 66.6 seconds to 100 seconds depending on the sampler location and the test conditions. After each test, the fluoride was chemically extracted from the filter in each cassette and analyzed to determine fluoride content. HF concentrations could be determined over a range from 0.3 to 42,000 ppm.

Photographic documentation was made with video tape recording from three different locations during the six tests. In addition, two framing cameras were used that took 35 mm pictures at 10 to 30 second intervals. During test 2-6, aerial photographs were taken from a helicopter approximately 500 m upwind of the release point and at an altitude of 500 m. Different types of recordings were utilized for different tests including video, still photos, and an infrared thermal scanner.

Table 6 - Summary of Goldfish Series

	Test 1	Test 2	Test 3
Released material	HF	HF	HF
Date	8/1/86	8/14/86	8/20/86
Duration (sec)	125	360	360
Spill Rate (kg/s)	27.67	10.46	10.27
Spill Mass (kg)	3459	3766	3697
Avg. Wind Speed @ 2m (m/sec)	5.79	4.04	4.80
Pasquill Stability Class	D	D	D

List of Further Reading for Goldfish Series

Blewitt, D.N., J.F. Yohn, R.P. Koopman, and Brown, T.C., 1987, "Conduct of Anhydrous Hydrofluoric Acid Spill Experiments," American Institute of Chemical Engineers, Proceedings, International Conference on Vapor Cloud Modeling, Boston, MA, Nov. 2-4.

Blewitt, D.N., J.F. Yohn, and D.L. Ermak, 1987, "An Evaluation of SLAB and DEGADIS Heavy-Gas Dispersion Models Using the HF Spill Test Data," American Institute of Chemical Engineers, Proceedings, International Conference on Vapor Cloud Modeling, Boston, MA, pp 56-80, Nov. 2-4.

Blewitt, D.N., J.F. Yohn, R.P. Koopman, T.C. Brown, and W.J. Hague, 1987, "Effectiveness of Water Sprays on Mitigating Anhydrous Hydrofluoric Acid Releases," American Institute of Chemical Engineers, Proceedings, International Conference on Vapor Cloud Modeling, Boston, MA, pp 155-180, Nov. 2-4.

11. DETERMINATION OF SPILL CONTROL AGENT EFFECTIVENESS IN MITIGATING VAPORS FROM HAZARDOUS AND TOXIC CHEMICALS

Sponsor: Ansul Company

Dates of Experiments: April 3-7, 1990

Chemicals released: Chlorosulfonic Acid, 65% Oleum, and Sulfur Trioxide

Description of experiments: During the first week of April 1990, a study of the effectiveness of vapor mitigation for three different chemicals was performed at the HSC. There are no known reports presented in the open literature and the author is not aware of any internal reports generated by the participants. From reviewing the limited amount of documentation available plus the data files, it appears that the objective was to investigate the evaporation rate for each of the three chemicals (chlorosulfonic acid, 65% oleum, and sulfur trioxide) under three different scenarios: (1) with no mitigation procedure applied, (2) with a foam blanket applied, and (3) with a combination of foam blanket and water applied.

The chemicals were placed in a square pan mounted on load cells that allowed determination of total amount of chemical released into the pan and monitor its weight change with time. Downwind concentration instrumentation was installed at three tower locations to measure the species released. The locations and heights of these sensors were not reported.

12. DETERMINATION OF AQUEOUS FOAMS EFFECTIVENESS IN EXTINGUISHING CHLOROSILANES FIRES AND VAPOR SUPPRESSION

Sponsor: Silicones Health Council, Inc.

Dates of Experiments: May 7 - May 14, 1990

Chemicals released: Trichlorosilane and Silicon Tetrachloride

Description of experiments: During the second week of May 1990, a series of experiments were conducted at the HSC to evaluate the effectiveness of aqueous foams in mitigating chlorosilane fires. There were no known reports presented in the open literature and the author is not aware of any internal reports generated by the participants. From reviewing the limited amount of information available it appears that either trichlorosilane and silicon tetrachloride were placed in a square pan. After filling the pan to a specified level, the chemical was ignited and then foam was applied for some duration that was probably sufficient to extinguish the fire. There appears to be more than a single type of foam applied but foam specifications are not provided. In some experiments the foam barrier is mechanically broken or swept back to allow exposure of the chemical to the atmosphere and reignition of the chemical is performed with additional foam application.

The dispersal pan was mounted on load cells that allowed determination of total amount of chemical released into the pan. Heat flux sensors were placed at locations downwind and crosswind from the pan containing the released material. These locations had two heights at which measurements were recorded, 3 and 6 ft above ground level. In addition, temperatures were recorded at three locations: (1) the air temperature approximately 3 ft above the pan bottom, (2) the reaction temperature approximately 3 inches above the chemical level, and (3) the chemical temperature approximately 2 inches above the pan bottom.

Apparently downwind concentration instrumentation was installed at various distances and heights to measure a species, which is not identified but the author assumes to be HCl. The locations and heights of these sensors are not reported.

13. CHLORINE VAPOR MITIGATION TESTS

Sponsor: Dow Chemical U.S.A.

Dates of Experiments: June 18-25, 1990

Chemical released: Liquid Chlorine

Description of experiments: During June 1990, Dow Chemical U.S.A. performed a series of experiments to collect data on the efficacy of aqueous foams and water sprays on suppression of chlorine vapors. The tests were run over a period of five days and involved releasing up to 150 lb/min of liquid chlorine into a 50 ft^2 insulated pan mounted on load cells. The supply cylinders from which the liquid chlorine was transferred were also mounted on load cells to measure material released. Temperature measurements were made at the pan and at downwind locations. As shown in Figure 14, fifty-five (55) chlorine sensors were mounted on seventeen (17) towers downwind of the release pan at heights of 5, 15 and 25 ft with some additional sensors at the 1 ft height. The towers were organized in three downwind arrays at downwind distances of 250, 500, and 750 ft from the release pan. Tower separation within an array was 150 ft. Two additional towers were located 0.5 mile downwind from the release pan, each with three sensors at heights of 5, 17, and 35 ft. The wind field measurements were made with five (5) stations located across the site, each had a cup-and-vane anemometer mounted at 2 m height to provide wind speed and direction. Visual records of the experiments were made with still cameras and a portable video camera.

A total of six (6) tests performed. Each involved transferring liquid chlorine from one or more chlorine 1-ton containers to the open pan. After the pool of liquid chlorine had stabilized and measurements were made of downwind concentration with no mitigation procedure applied, one of several different mitigation procedures was performed on the liquid pool. In the first and last tests, the only mitigation technique used was water spray nozzles to "knock down" the chlorine vapor cloud. In tests 2, 3, and 5 different vapor suppression foams were applied to the liquid pool surface in combination with water spray from the nozzle system and measurements were made of the downwind concentration to determine effectiveness of the procedure. Test 4 used no foam but did use the water spray nozzles and a portable water nozzles.

List of Further Reading for the Chlorine Releases

Thomerson, Jim, 1990, "Chlorine Vapor Suppression Tests", Internal report, Dow Chemical U.S.A., Chlor-Alkali Technology Center, A-1230, Freeport, TX 77541. Copies of this report and a short video may still be available from the Chlorine Institute, Inc., Washington, DC.

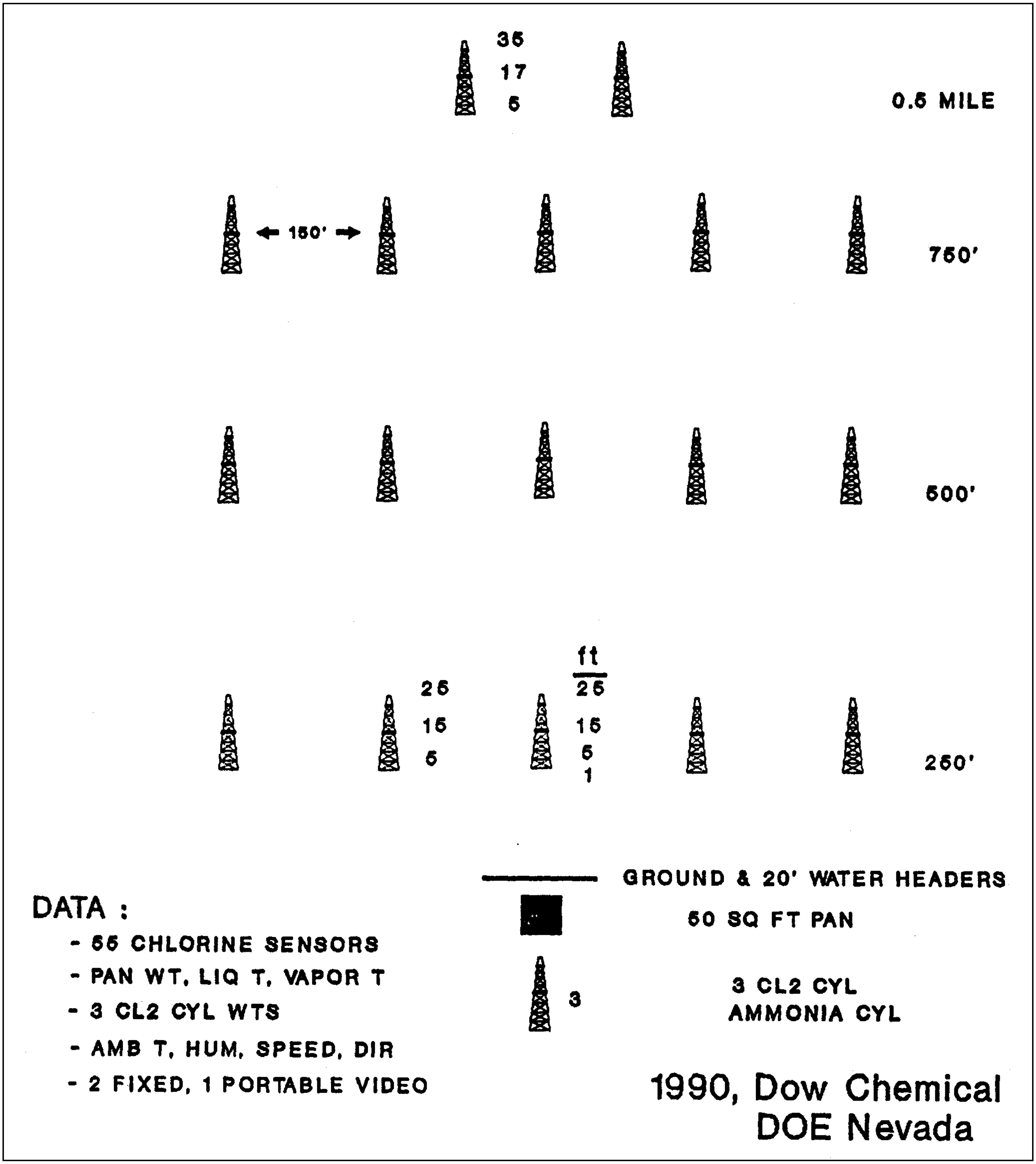

Figure 14 – Chlorine Vapor Mitigation Tests Configuration (Thomerson, 1990)

14. HYDROGEN FLUORIDE SUIT TESTS

Sponsors: U.S. Department of Energy, U.S. Department of Labor (OSHA) and U.S. Department of Transportation

Dates of Experiments: May 1, 1991 - July 25, 1991

Chemical released: Hydrogen Fluoride

Description of experiments: No documentation was available other than the data files, which don't describe the experimental objectives nor the equipment, test conditions, suits tested, or sequence of operations for these experiments. A report from earlier work conducted by LLNL at the HSC (Johnson and Swearingen, 1989) described a series of experiments that were performed to test totally encapsulating chemical protective (TECP) suits under realistic worst-case exposures to hydrogen fluoride (HF). The authors assume that the data files from 1991 where HF was the chemical tested and the 1992 data files where chlorine and ammonia were tested were similar.

The tests described earlier were conducted using a static mannequin on which the suits were mounted. Other tests utilized another mannequin that articulated at the waist to provide more realistic test conditions. The mannequins were fitted with internal chemical sensors to determine internal HF concentration and a compressed air system to allow simulation of breathing. Suits were exposed to various concentrations of the released chemical for periods of about 10 minutes.

List of Further Reading for the Hydrogen Fluoride Suit Tests

Johnson, J.S. and P.M Swearingen, "Exposures of Totally-encapsulating Chemical Protective Suits to High and Very High Concentrations of Hydrogen Fluoride along with Future Experimental Plans," Lawrence Livermore National Laboratory, UCRL-101717, 1989.

15. CHLORINE AND AMMONIA SUIT TESTS

Sponsors: U.S. Department of Energy, U.S. Department of Labor (OSHA) and U.S. Department of Transportation

Dates of Experiments: June 29, 1992 - July 24, 1992

Chemical(s) released: Chlorine and Ammonia

Description of experiments: See HF suit tests.

16. DUPONT MITIGATION WORKSHOP - DETERMINATION OF EFFECTIVENESS OF VARIOUS TECHNIQUES IN MITIGATING HAZARDOUS MATERIAL SPILLS AND TRAINING OF PERSONNEL TO MITIGATE HAZARDOUS MATERIAL SPILLS

Sponsor: E.I. du Pont de Nemours and Company

Dates of Experiments: April 7, 1992 - May 14, 1992

Chemical(s) released: 65% Oleum and Chlorosulfonic Acid

Description of experiments: During the spring of 1992, DuPont sponsored a mitigation workshop to evaluate the effectiveness of using certain mitigation techniques on spilled 65% oleum and chlorosulfonic acid. Different techniques and materials were evaluated while mitigating the released acid. The tests also provided an opportunity for industrial workers from facilities where these acids were used to have "hands-on" experience mitigating these released materials. There are no known publications or internal reports developed from these tests. The authors had access to some of the internal operations documents generated during the conduct of the tests and the following description is based on those documents and discussions with Brad Kulesza of DuPont. From this series of tests, DuPont has developed a workshop that is conducted at the HSC approximately every two years for their customers to participate in this type of mitigation training.

The acids were transferred into an open pan mounted on load cells to monitor the mass of acid released. The pan was instrumented with thermocouples (Type K) to determine the air temperature above the pan (height not known), the temperature of the reaction was measured approximately 5 inches above the bottom of the pan bottom, and the temperature of the liquid (acid) which was measured at 1.5 inches above the bottom of the pan. Ambient air temperature, humidity, wind speed and direction were also recorded during each test. Visual records were made using video cameras.

A number of different types of mitigation techniques or materials were tested and are listed in Table 7.

Table 7 – Materials Used During Mitigation Tests

Water	Foam - Universal Gold 3%
Water fog	Spill-X
Foam (not specified)	Spill-X-A
Foam – Universal Gold	Spill-X-A & Foam (not specified)
Foam – Ansul 3+3	Spill-X-A & Foam (not specified) & Water
Foam – National Vapor Shield-AC	

17. DRI/WRI/EPA CO_2–I EXPERIMENTS

Sponsor: Environmental Protection Agency

Dates of Experiments: July 22 - 28, 1993

Chemical released: Carbon Dioxide

Description of experiments: A series of four CO_2 vapor releases were conducted at the HSC during July 1993 by DRI and WRI personnel with support from the DOE site contractor, EG&G/EM, and EPA technical staff. This series was the first fieldwork in an EPA sponsored research program to better understand dense gas dispersion under stable atmospheric conditions. These experiments documented two facts: (1) a demonstrated methodology for collecting high-resolution concentration data and (2) that dense gas behavior could be exhibited by releasing as little as 1-2 kg/s of the heavier-than-air surrogate gas, CO_2.

In 1990, the U.S. Congress passed the Clean Air Act Amendments (CAAA), of which section 112(r) mandated the EPA to develop regulations requiring industrial facilities that stored, produced, or used certain threshold quantities of hazardous materials to create a Risk Management Program (RMP). The RMP was to address issues related to accidental releases of these hazardous materials, one of which was the prediction of the consequences of a release of these materials under a "worst case" scenario. The "worst case" scenario was defined as a Pasquill F stability with wind speeds of 1.5 m/s. Congress realized the available models to predict the consequences were unproven or tested for this "worst case" scenario and therefore also decreed that research should be conducted at the HSC to address this fact along with evaluating the effectiveness of emergency response to accidental releases, CAAA sections 103(f) and 901(h). This research program was to be carried out by the Desert Research Institute (DRI), Reno, NV and Western Research Institute, Laramie, WY and supported by the EPA and DOE.

In 1992, meetings at Research Triangle Park (RTP), NC between EPA, DRI, WRI, DOE, DOT, FEMA, and industry developed a consensus plan for addressing this research program. The first task was to demonstrate what was achievable at the HSC, these being:

- that high resolution (1 Hz or greater) concentration data from numerous sensors could be fielded at the HSC,
- that dense gas effects could be produced using CO_2 as a dense gas surrogate, and
- that it was possible to capture the required "worst case" conditions specified in the CAAA section 112(r).

Based on prior meteorological data, a transition from neutral to stable conditions could be anticipated during the period from just before until just after sunset at the Frenchman Flat site. This series of four CO_2 and tracer amounts of SF_6 were released during the late afternoon just prior to sunset. The releases lasted in duration from 70 to 265 sec with CO_2 vapor release rates from ~0.5 to 1.6 kg/s. The experiments had been designed to use a horizontal jet source but were changed very late in the program to simulate a ground level low-momentum source.

Liquid CO_2 was provided by BOC Gases in a portable 6-ton liquid storage tank that was connected to a 30-ton storage tank via a vaporizer to allow a large source of CO_2 vapor. The CO_2 vapor storage tank was connected to a 4-inch release line that extended to the original horizontal jet source that had a 6-inch control valve attached. The late modification to the source allowed an 18-inch flexible hose to be connected to a 1-m x 1-m release box that was buried below ground level such that the top of the box was at grade level, see Figure 15.

The mass of CO_2 released was computed by measuring the temperature and pressure of the 30-ton storage tank before, during, and after the release. Knowing the fixed volume of the tank, a mass calculation could be made to determine mass of CO_2 at any point during the tests. Temperatures, measured with Type K thermocouples, within the release system were made to determine if the release of CO_2 was isothermal.

In addition to the CO_2 released, a small measured and recorded amount of SF_6 was injected continuously into the release line during each release. The flow system was calibrated to release approximately 0.9 mg/s of SF_6.

Meteorological measurements were made on 24-m permanent tower installed at the HSC and instrumented by DRI during the early part of July 1993 to record data for this test and during the year to characterize the meteorology of the site. The 24-m tower was instrumented with a dedicated data acquisition system (DAS) that also provided analog outputs to the HSC's CCDAS when required during testing. These data were recorded every 10 sec during the testing periods. During the remainder of the year when the data was being archived for later analysis, the data was acquired every 10 sec and stored as engineering units as a 15 minute average. This data was automatically downloaded from the DAS via a modem connection to DRI's Data Processing Center in Reno (Coulombe, et al., 1994).

The tower was instrumented with eight (8) levels of R.M. Young Model QA-5305 anemometers to measure wind speed, direction (except during the CO_2 releases when the R.M. Young Model RE-5701 anemometers were used) and RTD air temperature sensors located at heights of 0.25, 0.5, 1, 2, 4, 8, 16, and 24 m. In addition, relative humidity measurements were made at three levels, 1, 4 and 16 m. Soil temperature was measured with a Fenwal Termistor at a depth of 7 cm near the tower and barometric pressure was measured at the base of the tower. Solar radiation and net solar radiation were measured at the 2 m height on a small tower located about 10 m from the tower. This tower was located approximately 95 m upwind of the source and about 55 m to one side of the centerline of the test grid.

In addition to the 24 m meteorological tower, there was an R.M. Young Model RE-5701 anemometer positioned at 5 m in front of the first gas concentration sensor array on the centerline at a height of 0.5 m. Seven cup-and-vane anemometers mounted at a 2 m height measured wind speed and direction and were placed around the test grid to provide measurements of the wind field.

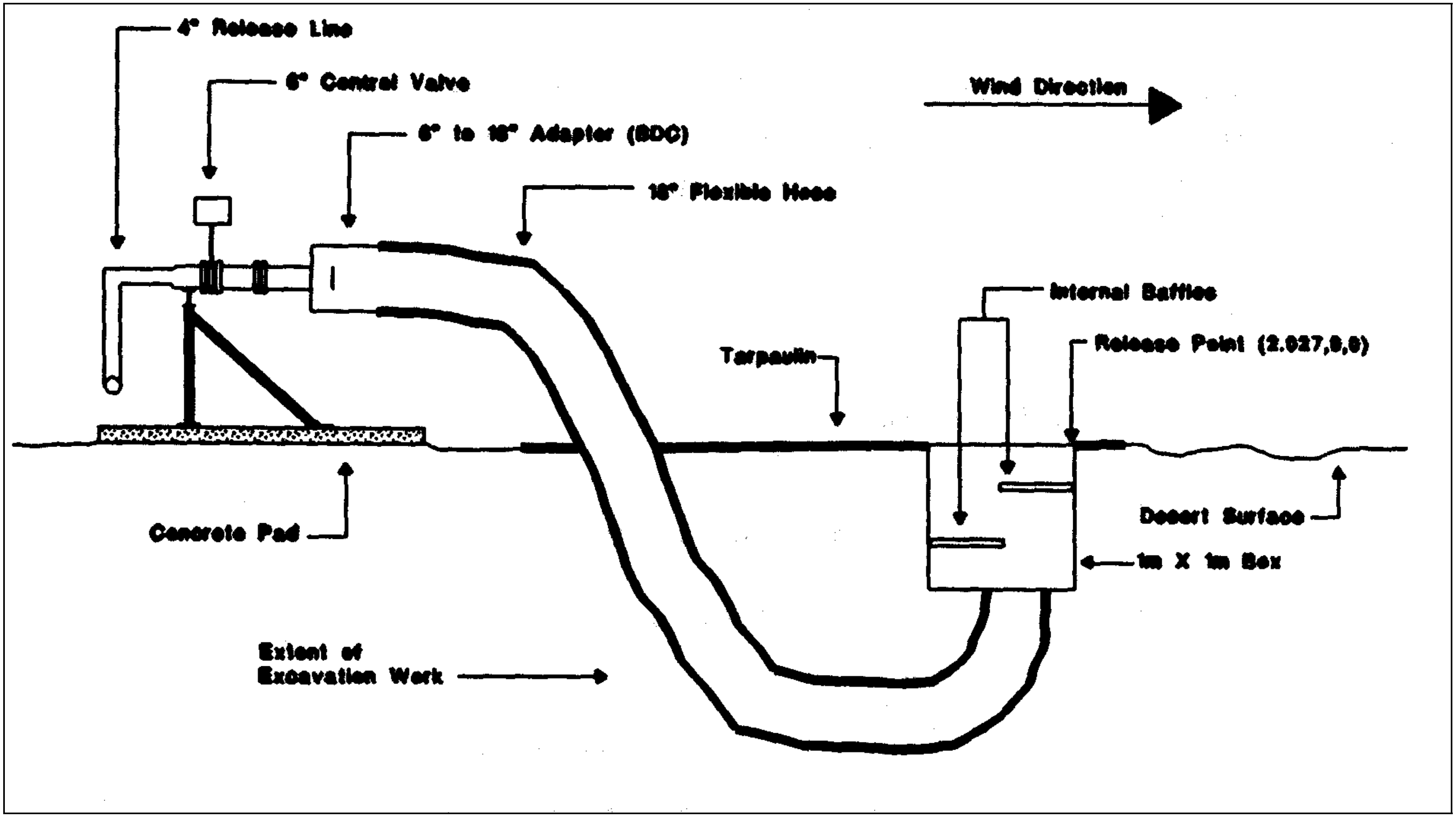

Figure 15 – Ground Level Low Momentum Source (Egami, et al., 1996)

The dispersion of CO_2 was captured by a gas concentration sensor array containing thirty-seven (37) real-time gas sensors at 40 m downwind from the source. The sensors were positioned on towers across a total distance of 30 m to either side of the centerline of the array. The locations and the range of the sensors are depicted in Figure 16. The position of the ground level source in front of the original position of the horizontal jetting source caused the distance from the source to the first instrument array to change from 40 m to approximately 38 m. A second gas concentration sensor array containing three (3) sensors was located 100 m downwind from the source. The sensors were located at a height of 0.2 m with one on the centerline and the other two at 6.5 m on either side of the centerline.

The sensors were solid-state IR sensors that had a fast response time for changes in CO_2 concentration (< 1 sec). They could be ranged for different full-scale concentrations of CO_2 and for these experiments two ranges were used, 0-1% and 0-10%. They provided a 0-5 VDC output that was not linear. Along with the fast response CO_2 sensors, gas sampling bags were installed on the 40 m gas concentration array. The gas sampling bags were 20 liter 2 mil Tedlar sample bags installed at 43 locations on this array. Two bags were installed upwind of the source to measure background of CO_2 and SF_6. The sample in each bag was assumed to be representative of the average ambient air passing a specific sampling point during the sampling period. The implementation of the gas sampling bags allowed for filling to be control by a remote signal to solenoid valves from the CCDAS. After each release, the bags were subjected to CO_2 and SF_6 analysis. This was done to provide a crosscheck against the real-time solid-state CO_2 sensors and for calculating a mass balance for each release.

Table 8 provides a summary of the tests conditions.

Table 8 – Summary of DRI/WRI CO_2-I Experiments

	Test 1	**Test 2**	**Test 3**	**Test 4**
Date	7/22/93	7/26/93	7/27/93	7/28/93
Time	18:55:01	19:41:01	19:30:00	19:46:00
Duration (sec)	179	70	265	265
Mass of CO_2 Released (kg)	81.9	112.9	171.9	165.0
Mass of SF_6 Released (mg)	163.4	63.6	238.2	240.0
CO_2 release rate (kg/s)	0.458	1.613	0.649	0.623
Wind speed @ 1 m height on 24 m tower (m/s)	N.R.*	N.R.	3.19	5.49
Pasquill Stability	N.R.	N.R.	E	D
CO_2 Mass Balance (%) based on continuous sensors	114	53	94	99
CO_2 Mass Balance (%) based on Gas Sampling Bags	95	65	91	97
SF_6 Mass Balance (%)	105	15	53	117

* N.R. – not reported

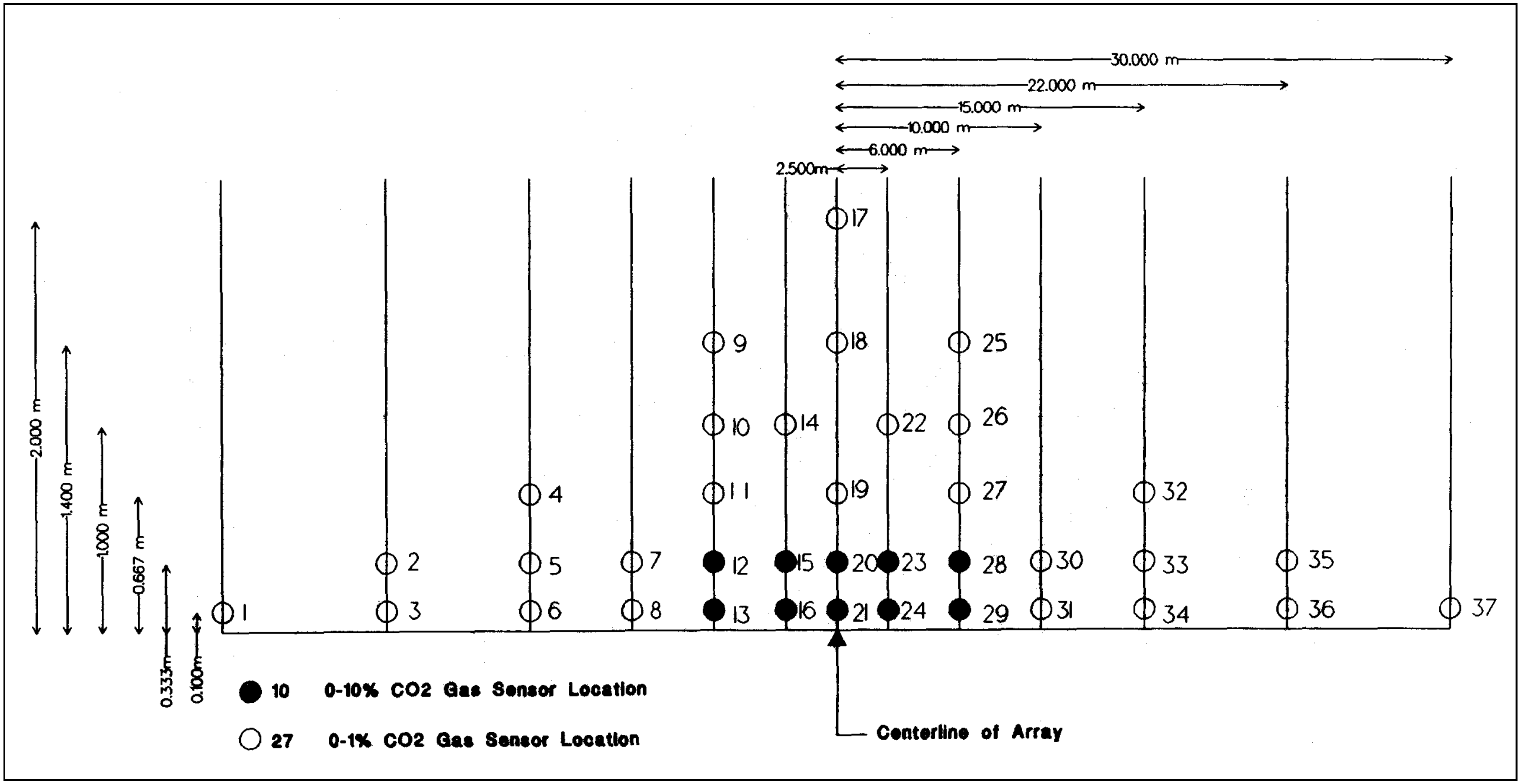

Figure 16 – Real-time Sensor Locations for DRI/WRI CO_2–I Experiments (Egami, et al., 1996)

List of Further Reading for the CO_2-I Experiments

Briggs, G.A., September 1995. "Field-measured dense gas plume characteristics and some parameterizations." International Conference and Workshop on Modeling and Mitigating the Consequences of Accidental Releases of Hazardous Materials. New Orleans, LA, 26-29 September 1995, AIChE.

Coulombe, W., J. Bowen, D. Freeman, R. Egami, B. Cristani, S. Schmidt, D. Sheesley, B. King and T. Routh, November 1994, "24M Meteorological Tower Data Report Period: August through December, 1993," DRI Doc. No. 94-305.D3, DRI, P.O. Box 60220, Reno, NV 89506-0220.

Egami, R., W. Coulombe, J. Bowen, D. Freeman, J. Watson, D. Koracin, D. Schorran, B. Zielinska, D. Sheesley, J. Nordin, T. Routh, and B. King, 24 May 1996, "Characterization of Carbon Dioxide Releases−Experiment One." DRI Doc. No. 93-3305.3F, DRI, P.O. Box 60220, Reno, NV 89506-0220.

18. KIT FOX SERIES

Sponsors: U.S. Environmental Protection Agency, U.S. Department of Energy and Petroleum Environmental Research Forum Project 93-16

Dates of Experiments: August 22 – September 15, 1995

Chemical released: Carbon Dioxide

Description of experiments: In August and September 1995 a series of dense gas dispersion experiments were conducted by WRI and DRI as a continuation of the July 1993 DRI/WRI CO_2-I experiments. Funding for the Kit Fox collaborative research was provided by WRI with DOE Jointly Sponsored Research funds, together with the EPA's Office of Research and Development and Chemical Emergency Preparedness and Prevention Office, and the Petroleum Environmental Research Forum (PERF) Project 93-16.* The project, using CO_2 as a dense gas surrogate, was designed to develop a database of measurements during heavier-than-air releases that would simulate the "worse-case" scenario requirement of the CAAA 112(r). The gas releases were conducted under three different surface roughness configurations during neutral and stable atmospheric conditions. The Kit Fox field experiments required data on wind speed, ambient turbulence, wind direction, wind profiles as a function of height (from which a surface roughness can be calculated), temperature profiles as a function of height (from which a Monin-Obukhov length can be calculated), and humidity. A PERF 93-16 concern was the along-wind dispersion coefficient (σ_x) at the leading and tailing edge of the cloud and model validation of short duration releases, and therefore, finite-duration releases (puffs) were incorporated into the test matrix. The DRI/WRI CO_2–II Experiments (Coulombe, et al., 1999) were the smooth desert surface configuration of the Kit Fox Series conducted in September 1995, after the enhanced roughness portions of the experiments were completed in August.

The modeling, laboratory and wind tunnel studies leading to the final design of the field project were documented by WRI (Sheesley, et al. 1995) and are summarized below:

- The roughness obstacles, called the Equivalent Roughness Pattern (ERP), simulate a refinery tank farm at about 1:10 scale and were developed from the Cermak Peterka Petersen, Inc. (CPP) (Petersen and Cochran, 1995) wind tunnel work. The roughness pattern that simulated the surface surrounding a typical tank farm/refinery called the Uniform Roughness Array (URA) at about 1:10 scale was developed from the EPA wind tunnel work at Research Triangle Park (Snyder, 1995).

- The participants recognized that a full-scale mockup representing a "typical" refinery or chemical plant covering an area of about 100 acres (0.5-km x 1.0-km) would be impractical. The design used the techniques demonstrated at wind tunnel scale to

* The 10 companies making up the Petroleum Environmental Research Forum 93-16 Project are Allied Signal Corporation; Amoco Corporation; Chevron Research and Technology Co.; CITGO Petroleum Corporation; Clark Oil and Refining Co.; Exxon Research and Engineering Co.; Marathon Corporation; Mobil Research and Development Co.; Phillips Petroleum Co.; and Shell Research and Development Co.

demonstrate relationships to reproduce and/or predict full-scale phenomena at a scale that could be constructed in the field. By selecting appropriate scaling factors, a reduced-scale simulation of a dense gas release could be made to represent a release over a full-scale, real-world surface roughness outlined by Dr. Gary Briggs (EPA Technical Advisor). The principal investigators of WRI, PERF, and EPA, determined that a 1:10 physical scale and a 1:6 time scale simulation could be carried out in the field.

- The CPP and WRI 1:10 scale model development for the ERP was sized to simulate an artificial boundary layer or mixing depth that would be generated by a refinery with process towers, buildings, pipe racks and tanks. To achieve this 1:10 scale model, each ERP baffle was about 2.4 m high with a roughness length, z_0, of about 0.2 m set up in a rectangular grid with a cross-wind dimension of 39 m and an along-wind dimension of 85 m (See Figure 17 and 18).

- The rectangular grid, measuring 314 m by 120 m, surrounded the central ERP grid. This URA was constructed to simulate a typical grass and low brush area surrounding an industrial facility. Again, the field scale was about 1:10. The URA baffle elements are about 0.2 m high with a calculated roughness length, z_0, of about 0.02 m (i.e. the URA z_o was about 10% of the ERP z_o). The crosswind size was designed to be large enough to contain the lateral spread of dense gas clouds based on tests conducted in the CPP wind tunnel. The along-wind dimension extended upwind of the ERP far enough (89 m) so that the boundary/mixing layer would develop in the ERP and URA roughness up to heights of about 5 to 10 m at the source position.

- To reduce the number of URA elements required in the upwind fetch to develop atmospheric boundary layer depth in the simulated refinery grid, a wind tunnel technique was used. "Trip spires" were incorporated into the test grid upwind of the release point to decrease the distance required for boundary layer development.

The sensors for the Kit Fox tests included high-concentration and low-concentration CO_2 sensors. A low-concentration sensor could measure concentration/spanned from 0-2,000 ppm (0-0.2%) up to 0-20,000 ppm (0-2%) full-scale, and a high-concentration sensor could be spanned from 0-50,000 ppm (0-5%) up to 0-150,000 ppm (0-15%) full-scale. The response time was less than one second for the high-range sensors and about 3-4 seconds for the low-range sensors.

The sensors were laid out in four arrays located downwind from the source and oriented perpendicular to the centerline of the predicted transport course of the cloud. The roughness conditions were: (1) ERP+URA, (2) URA-only, and (3) no roughness (or smooth desert surface). The array distances downwind and sensor concentration ranges were chosen for a 4-kg/s CO_2 release for the roughness condition with the ERP+URA, based on 1993 WRI/DRI CO_2–I experiments data and reported modeling calculations (both SLAB and HEGADAS v3.0+ models were used). A 1.5 kg/s release rate was used for the URA-only experiments.

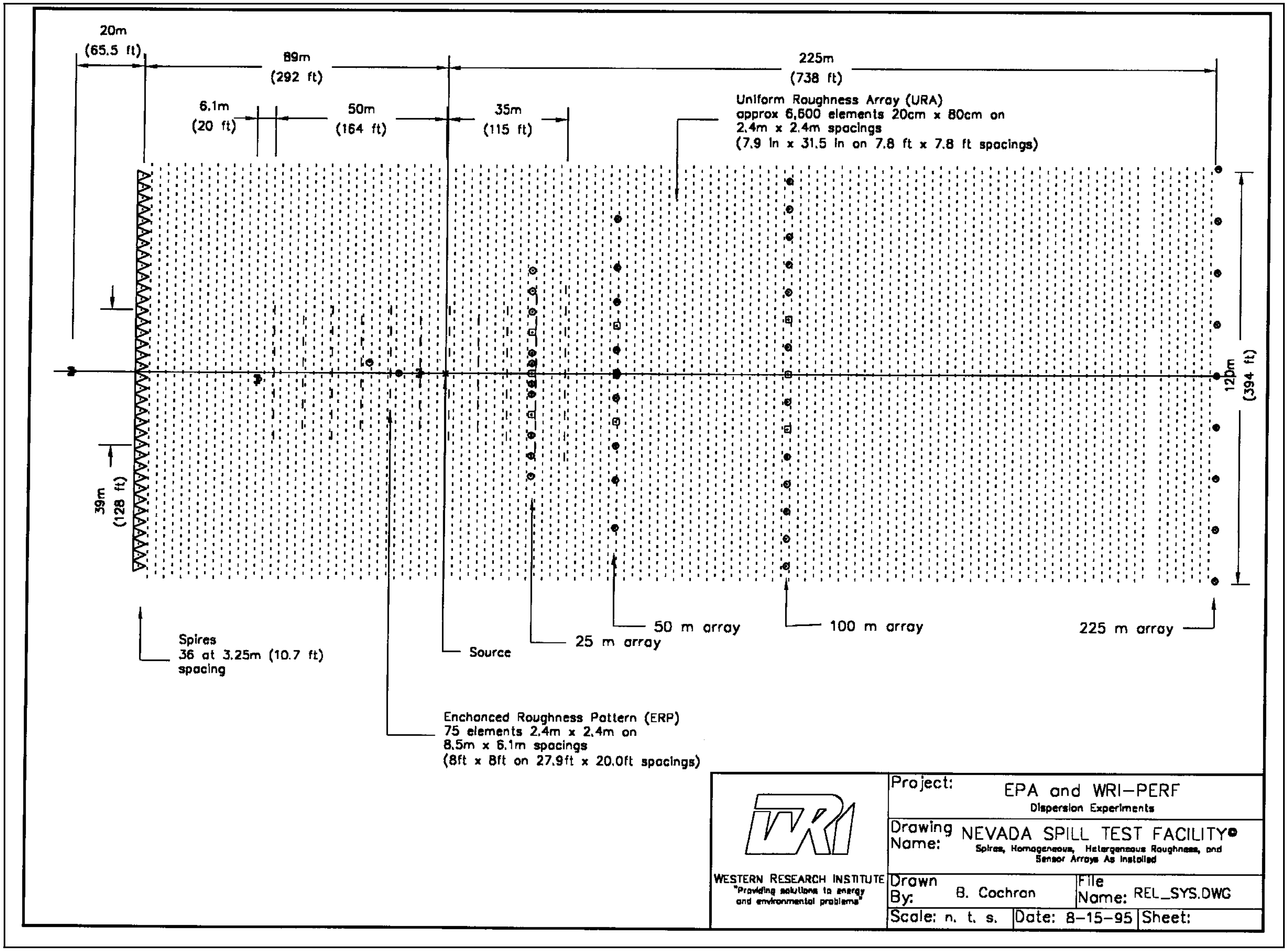

Figure 17 - Source, Monitoring Array, ERP, and URA Locations (Sheesley, et al., 1998a)

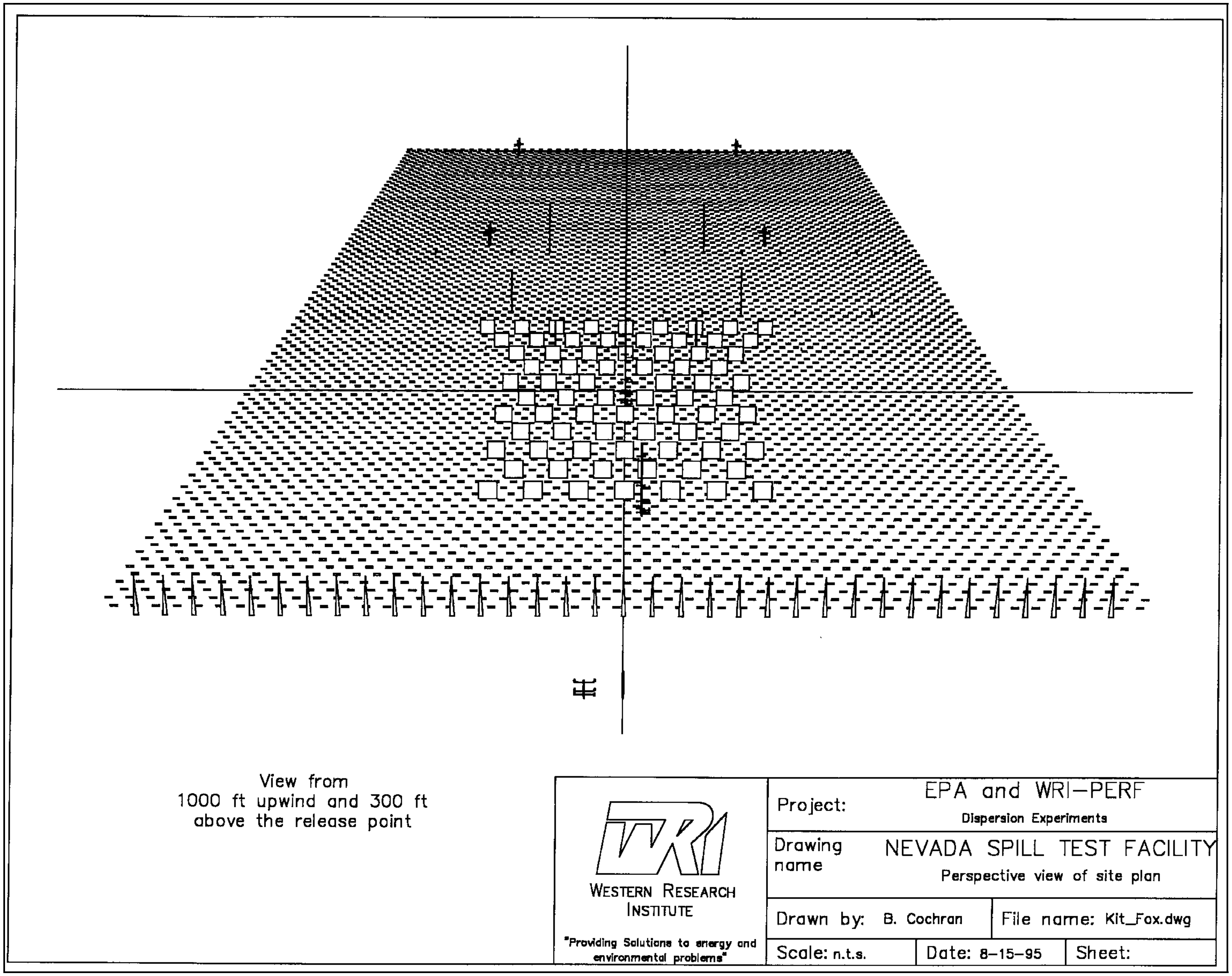

Figure 18 - NTS Experimental Arrays Viewed from Upwind Location (Sheesley, et al., 1998a)

To provide an independent crosscheck of continuous sensor performance, during a release on a test day, an integrated bag sample was co-located at selected Nova sensor locations. A high correlation between the integrated bag samples collected over a 4 to 9 minute time period and the integrated response from the corresponding Nova sensor for the same time interval provided a high confidence in the real-time sensor results.

A Kit Fox test objective was to provide adequate instrumentation to measure meteorological conditions both over the flat desert surface and within the dispersion grid containing the ERP and URA roughness. The meteorology measurements made on the permanent 24-m tower located southwest of the test grid were wind speed, wind direction, and temperature measured at 0.25, 0.5, 1, 2, 4, 8, 16, and 24 m above the ground. Solar and net radiation were also measured 2 m above the ground, 20 m south of the tower. Barometric pressure and soil temperature (1 cm below the surface) were measured near or at the base of the tower. Relative humidity was measured at 1, 4, and 16 m. Additional meteorology data were recorded on an 8-m tower with five levels of wind speed, direction, and air temperature (Tower 2) located on the nominal 230° centerline in the URA; a 8-m tower, also recorded five levels of wind speed, direction, and air temperature (Tower 4) in the URA on the centerline downwind of the last obstacle (ERP); and four additional wind direction and speed measurements on 2-m high masts near the 100-m and 225-m arcs. Another short meteorology tower (Tower 1) with three anemometers and temperature sensors was located upwind of the spire row or 110 m upwind of the source to be in a location in the flat desert upwind from the influence of the Irwin spires. The locations of the meteorology towers are shown in Figure 19.

Sonic anemometers were provided by EPA-DRI/WRI and the U.S. Army Dugway Proving Grounds (DPG) and WRI. The EPA-DRI/WRI instrument and three of the DPG instruments were 3-axis instruments capable of measuring velocity fluctuations in the x, y, and z directions (u', v', and w'). Six other DPG instruments were 2-axis instruments that measured velocity fluctuations in two directions (u' and v').

The CO_2 release system was designed, constructed and tested to provide a single source characteristic; a gas release velocity of less than or about 1 m/s to minimize vertical momentum. The system also provided gas temperature near ambient temperature, release rates of 1.5 kg/s or 4.0 kg/s, rapid on/off (less than one second), sufficient volume for a series of finite-duration (puff) and continuous releases in one evening of tests, and volume recharge logistics to provide for consecutive test days. The vapor storage tanks were recharged from a liquid carbon dioxide container and vaporizer supplied by the vendor, BOC Gases. Recharging took about eight hours and was done during the previous night or morning of a test day.

The major components of the release system were:

- the existing HSC facility large volume tanks, with a total capacity of 204 m^3 (7,210 ft^3) and a 236 m (500 ft) long 30.5 cm (12 inch) diameter release line,
- a 177-m (580-ft) extension to the existing release line,

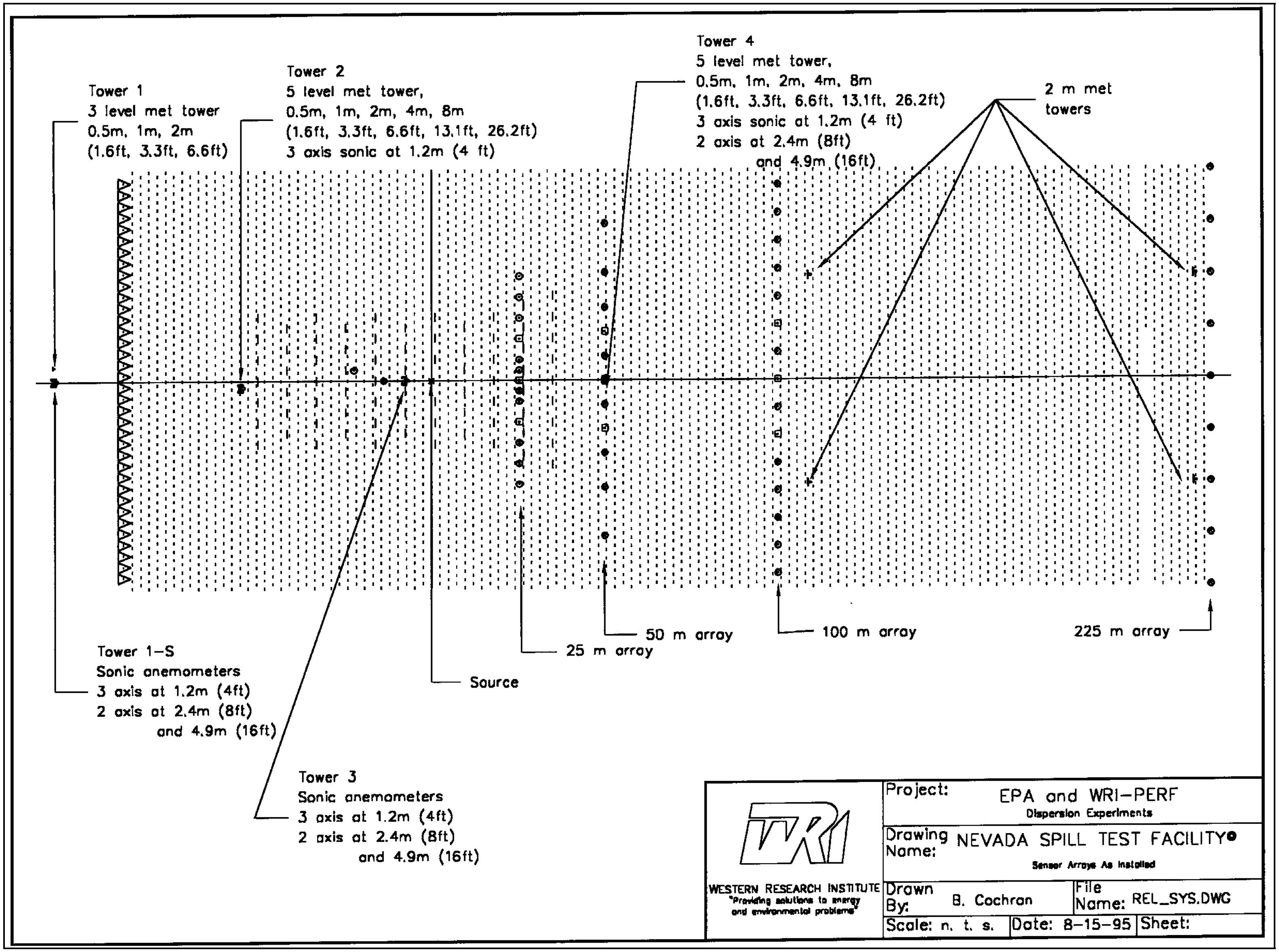

Figure 19 - Locations of Meteorological Towers within the ERP and URA (Sheesley, et al., 1998a)

- the 1.5 m by 1.5 m by 1 m deep release box connected to control valves, and flow measurement system all below ground level, and
- the release box doors at the ground level opening to obtain a rapid on/off.

Three independent methods of measuring released CO_2 vapor were used. The first was the measurement of carbon dioxide by a vortex shedding flow meter, located just upstream of the 10.2-cm or 15.2-cm (4-in and 6-in) butterfly control valves. The second method was the measurement of pressures and temperature at a 11.43-cm (4.5-in) orifice installed downstream from the butterfly valves and recorded. The third was the continuous recording of supply tank pressure and temperature by the HSC's CCDAS and calculation of the total mass change during a test day.

From August 22 to August 31, WRI conducted 70 releases. Tests were made during the late afternoon and early evening as the strong and predominately southwest winds diminished and the atmospheric stability transitioned from neutral to very stable. Neutral conditions (Pasquill D) were achieved with winds speeds between 3-5 m/s, stable conditions (Pasquill E) in the 2-3 m/s range and very stable (Pasquill F) in the 1-2 m/s range. Release duration varied between 2-5 minutes for the continuous releases and 20 sec for the finite-duration (puff) releases. On a test day when favorable meteorological conditions were present, as many as 14 gas releases were conducted during one evening of operations.

These tests were conducted under two separate surface roughness configurations. The first series, from August 22 to 28, had the ERP+URA roughness elements installed. This was to simulate the refinery with its surrounding low vegetation. During the morning of August 29, the large obstacles (ERP) were removed and from August 29 to 31 tests were conducted with an intermediate roughness configuration represented by the URA-only elements.

During the week of September 4 to 8, the URA elements were removed and a week of releases with a smooth desert surface configuration were conducted from September 11to 15. These smooth desert surface experiments are described in a separate report by DRI and WRI (Coulombe, et al., 1999).

The August enhanced roughness tests operations resulted in 74% (52 releases) of all releases being suitable for further data reduction, processing, and validation. Table 9 provides a matrix of the releases in the Kit Fox enhanced roughness database with respect to surface roughness configuration, stability, and duration of release (continuous vs. puff).

Table 9 - Kit Fox Field Demonstration Project Test Matrix

Pasquill	ERP+URA		URA-only	
Stability	Continuous	Puffs	Continuous	Puffs
D	T5r3*	T2r1,T3r1,T3r2, T3r3,T5r1,T5r2	T6r4,T6r5,T6r6, T7r2,T7r3,T7r5, T8r5,T8r8,T8r11	T6r1,T6r2,T6r3,T7r4,T7r6,T7r8, T8r1,T8r2,T8r3,T844,T8r6,T8r7, T8r9,T8r10,T8r12
E	T2r5,T5r4	T3r4,T5r5	T6r9,T7r9,T7r12	T6r7,T7r10,T7r11
F	T3r5,T4r4, T5r8	T3r6,T3r7,T4r3, T5r6,T5r7		T6r8,T7r13,T7r14

*The naming convention for the individual releases was TXrY, where 'X' is the test day and 'Y' is the sequential release for that test day.

List of Further Reading for the Kit Fox Series

Coulombe, W., J. Bowen, R. Egami, D. Freeman, D. Sheesley, J. Nordin, T. Routh, and B. King, 13 May 1999, "Characterization of Carbon Dioxide Releases–Experiment Two." DRI Doc. No. 97-7240.F, DRI, P.O. Box 60220, Reno, NV 89506-0220.

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