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1.0 INTRODUCTION

This is the final report for the Phase I R&D effort "*Marrying Commercial-off-the-shelf and Government-off-the-shelf Equipment for Tracking Chemical Releases*". The result of this effort has produced the design of a system called the Chemical Cloud Tracking System (CCTS).

The CCTS that was designed meets the Phase I goal of designing a system to track chemical releases using as many off-the-shelf components as possible. The implementation suggested in Section 7 is 98% off-the-shelf hardware and 80% off-the-shelf software. Because the CCTS is composed of off-the-shelf components which have already been proven, there can be no doubt about the technical feasibility of the integration of the components into a working CCTS. The technical risk associated with the effort is very low.

In Section 2, the objective of Phase I is discussed, and Section 3 points out that there are no technical difficulties in achieving the ultimate objective of building a cloud tracking system. Sections 4, 5, 6, and 7 describe the engineering process, from requirements (Section 4) to design (Section 5) to choice of components for implementation (Sections 6 and 7). The software that was implemented in Phase I is described in Section 8. Finally, the report wraps up with a matrix that cross references the tasks from the original proposal to the section in this final report that is the deliverable for that task.

2.0 PHASE I OBJECTIVES

The overall goal of the Phase I work was to produce a design that could be implemented in Phase II. This was accomplished.

During the Phase I research, two events occurred which significantly affected the final CCTS design. First, MESH made arrangements to replace the M21 with an alternate standoff sensor. Second, the way the CCTS would be used at Dugway was considerably different than what MESH had originally proposed.

2.1 ILSCAD

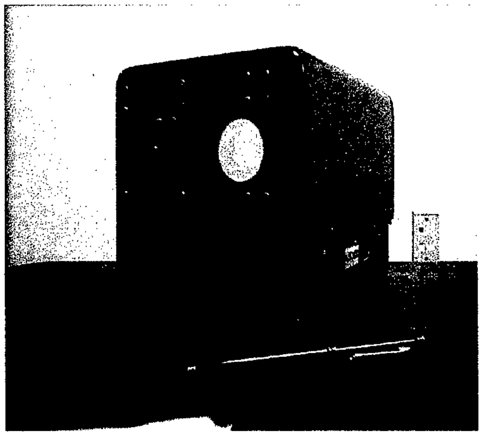

Figure 1 ILSCAD.

The original solicitation in May 1999 had suggested using the M21 as the basis for the CCTS. However, shortly after award of the Phase I, MESH contacted the technical staff of the JSLSCAD team regarding what their plans were for the original ILSCAD instruments (Figure 1) that were used during the research phase of the JSLSCAD program. The JSLSCAD team felt that since the production JSLSCAD instruments were soon to be delivered, they would no longer be needing the ILSCADs and were willing to transfer them to Dugway. The use of ILSCADS had several advantages over including the M21s in the CCTS.

1. The M21 is type classified military equipment and as such, would be subject to recall by front line units in the event of a conflict.
2. The ILSCAD is significantly smaller, lighter and lower power than the M21.
3. MESH had an off-the-shelf interface developed for the ILSCAD. The interface to the M21 would have to be developed.
4. The Block Model 90 and Model 100 are in production and available off-the-shelf (these are the newest versions of the ILSCAD and the interface is identical). Should it be desirable to purchase more sensors in the future, they would be available. Also, Block will service existing instruments. M21s are no longer manufactured and repairing them may be a major problem.

MESH was directed by Dugway to change the CCTS design so that the standoff sensor would be the ILSCAD.

2.2 CCTS Design

MESH's original Phase I proposal had treated the CCTS as a static piece of equipment. It was assumed that a specification for the CCTS would be written and then the hardware designed to meet that spec. However, in discussions with Dugway, it became obvious that no single configuration of sensors could meet all of the uses that were envisioned for the system. The size of the area in which the cloud was to be tracked varied, in some cases so large that the sensors would have to be vehicle mounted so they could be moved downwind with the cloud.

The accuracy and precision required also could not be defined since it depended on the unit being tested. Because the CCTS could not be specified in advance, the way that MESH executed Phase I also was changed.

Table 1 shows the original work plan to complete Phase I. The CCTS that resulted would have had a fixed number of M21 standoff sensors (probably two as suggested in the solicitation). Table 2 shows the revised work plan to produce a scalable CCTS (i.e. any number of standoff and/or point sensors can be attached). For the scalable CCTS, it was not necessary to derive the parameters ahead of the hardware design. The model is no longer a design tool; it becomes a planning tool for the test engineer to configure the CCTS for the particular test he is running (number of sensors, placement of sensors, wind direction, etc.). As a result, the hardware design could be done without modeling the CCTS first and was moved up to Step 2 of Phase I.

Table 1 Original Phase I Plan to Build a Fixed CCTS.

Step 1	Write CCTS requirements including accuracy and precision.
Step 2	Model the CCTS to find number of sensors required to meet requirements.
Step 3	Design CCTS

Table 2 Revised Phase I Plan to Build a Scalable CCTS.

Step 1	Write CCTS requirements without specifying accuracy and precision.
Step 2	Design CCTS to be scalable.
Step 3	Build a software model of the CCTS to be used as the planning tool.

The Phase I CCTS requirements are included in this proposal as Section 4. The Phase I detailed design is included as Section 5.

3.0 ESTIMATES OF TECHNICAL FEASIBILITY

In the Phase I proposal, ten areas of technology were listed essential to building a successful CCTS. We claimed at that point that, because of MESH's extensive background in these areas, the project was an integration effort and "since MESH has successfully demonstrated each of the ten areas already, this integration effort has very little risk".

In the ten months since the original proposal was written, all the work that MESH has accomplished (both on the SBIR Phase I and other chemical sensing activity) has reinforced our conviction that all aspects of integrating a CCTS are well understood by MESH personnel or our subcontractors (Litton and Block). In fact, a larger portion of the system is commercially available now than ten months ago, reducing risk further. Our estimate of the off-the-shelf content versus custom content is shown in Table 3. The 2% of the hardware that need to be built is custom brackets to hold CSS to the tripod and custom cables to meet Dugway's length requirements. The 20% of the custom software is to merge existing software packages into a smoothly functioning program.

Table 3 Estimated Content of CCTS

	Off-the-shelf	Custom-built	Total
Hardware	98%	2%	100%
Software	80%	20%	100%

4.0 CCTS REQUIREMENTS

The goal of building equipment to track chemical releases is to provide "ground truth" to Dugway. But, as MESH discovered during technical discussions with government personnel, "ground truth" at Dugway has different meanings depending upon what is being tested. Therefore, the CCTS that is designed and built must be able to accommodate a wide variety of uses which include:

- A cloud location map, but concentration information is not required
- A cloud concentration map
- A measurement of concentration-pathlength along one or more lines of sight

The accuracy of the measurement in any of these scenarios will depend on the scope of instrumentation used in the CCTS. To get the high detailed map that a "CAT" scan gives requires hundreds of views of the head. The same applies to the cloud tracking system. Using 4 FTIRs on tracking stands will give a more accurate picture of the cloud than just using 2.

Therefore, it is inappropriate to define a requirement for accuracy for CCTS. Instead, the requirement is that the CCTS configuration be scalable. That is, the number of FTIRs can be changed at will to allow the equipment that is fielded to match the needs of the particular field trial being conducted.

The following is the requirement list for the CCTS:

4.1 Real Time or Near Real Time Output (Required = 30 seconds) (Desired = 10 seconds)

The CCTS will provide near real time output of the cloud map. The maximum time from any sensor reading until that reading is presented graphically shall be 30 seconds. The desired delay from sensor reading to display is 10 seconds.

4.2 Cloud Mapping (Cloud Boundary) (Cloud Concentration)

The CCTS cloud mapping software will take the real time inputs from the various instruments and will perform data fusion. The output will be a map overlay showing either:

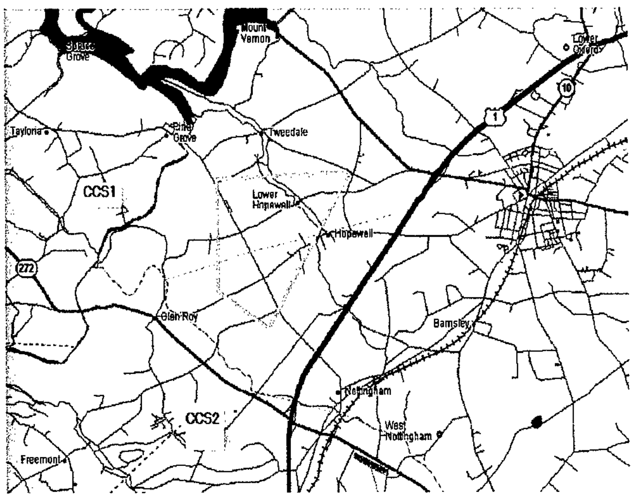

Figure 2 Example of Chemical Cloud Boundary Map.

a) Cloud boundary - A line is drawn around the edge of the cloud. Figure 2 shows an example of a cloud boundary map. This CCTS has only 2 standoff sensors and draws a four sided polygon. More sensors will increase the degree of polygon drawn and refine the cloud boundary. The sensor output for this map is detections only; quantitative measurements are not required.

b) Cloud concentration - Detail is shown inside the cloud boundary to illustrate concentration profiles.

c) Measurement of concentration-pathlength (CL) along one or more lines-of-sight.

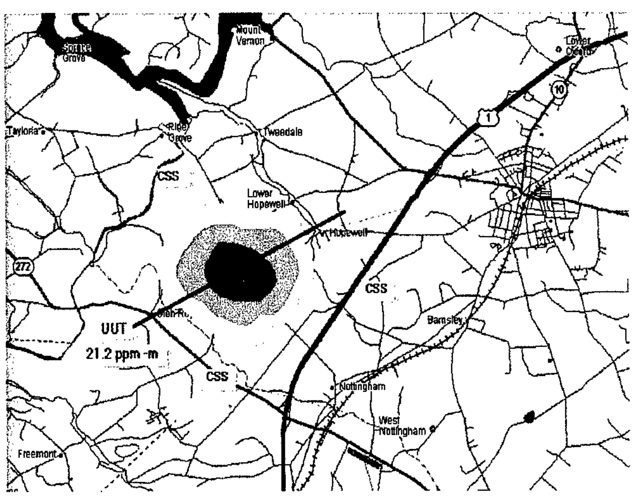

Figure 3 Example of Chemical Concentration Map with a Unit Under Test.

Figure 3 shows an example of a concentration map produced by tomographic techniques applied to three standoff sensors outputs. The map overlay is false colored to indicate the concentration level. The CL of the chemical in the field of view of the unit under test (UUT) can be calculated from the cloud concentration map. Also shown in Figure 3, a UUT is placed on the map with a particular field of view (FOV). The CL of the FOV can be updated in real time, even taking into account scanning by the UUT.

4.3 Accuracy and Precision (Scalable)

The CCTS accuracy and precision shall be a function of the physical configuration and number and type of instruments used. The more FTIRs used, the better the accuracy. Adding point sensors will also improve the accuracy.

4.4 Types of Sensors

(Required = Standoff)
(Desired = Standoff and Point)

The CCTS shall accept instrument readings of two types:

a) Concentration-pathlength
   This reading will come from the FTIR type instrument. The values must have units of mg/m^2 or ppm-m.

b) Concentration
   This reading will come from point sensor type instruments. The units will be mg/m^3 or ppm.

Both types of sensors must produce an estimate of the error in the measurements.

4.5 Mobile Sensors

The CCTS must allow for some of the sensors to be mobile (i.e. vehicle mounted).

4.6 Accuracy Prediction for a Particular Configuration of CCTS

A planning tool will be provided that can be used to estimate the accuracy of a particular configuration. This software program will be useful during planning for field trials. The location of the instruments and the number of instruments may be adjusted in the planning tool to achieve the desired result for the particular test being run.

5.0 CCTS DETAILED DESIGN

The CCTS hardware detailed design and the CCTS software high level functionality are given in this section.

5.1 CCTS Overview

The CCTS has five major subsystems:

1. Chemical Sensor Subsystem (CSS)
   FTIR - LSCAD + calibration + scanning
2. Map Generator Subsystem (MGS)
   human interface
3. Communications Link (COMMLINK)
   must allow - mobile, point sensors, other sensors
4. Other Sensors (OTHER) - allows point sensors and other types of chemical standoffs to be included
5. Power (POWER) - provides power to all equipment

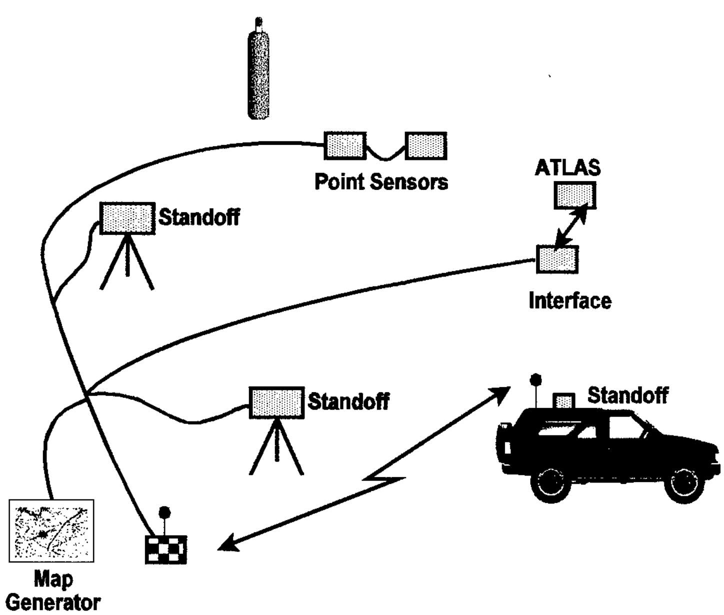

Figure 4 CCTS Subsystem.

5.2 Chemical Sensor Subsystem

The function of the CSS is to scan the cloud being tracked and report information about the cloud to the MGS over the COMMLINK. It has the following characteristics:

- Receives scan pattern from MGS
- Executes the scan pattern autonomously
- Is self calibrating
- Sends a report to MGS every time a new concentration pathlength (CL) has been measured. Included in report are:
  - chemical detected } Measurement
  - CL of chemical detected
  - error in CL measurement
  - latitude } CSS Location
  - longitude
  - altitude } Direction Aimed
  - azimuth
  - elevation
  - instrument status } Status
  - communication status
- Can operate either step and stare or measure while scanning
- Can adjust integration time of measurement (i.e., coadding)
- Is rugged enough to withstand environmental temperature extremes of -32°C to 49°C while operating

The parts of the CSS are shown in Figure 4.

5.2.1 Embedded Processor

This is the controller for the entire unit. It is a Pentium class ruggedized processor. It has the following hardware:

- Interface printed circuit for connection to the FTIR
- Four or five serial ports for:
  - tracker
  - FTIR
  - COMMLINK (Ethernet may be substituted for COMMLINK)
  - optional GPS
  - optional compass

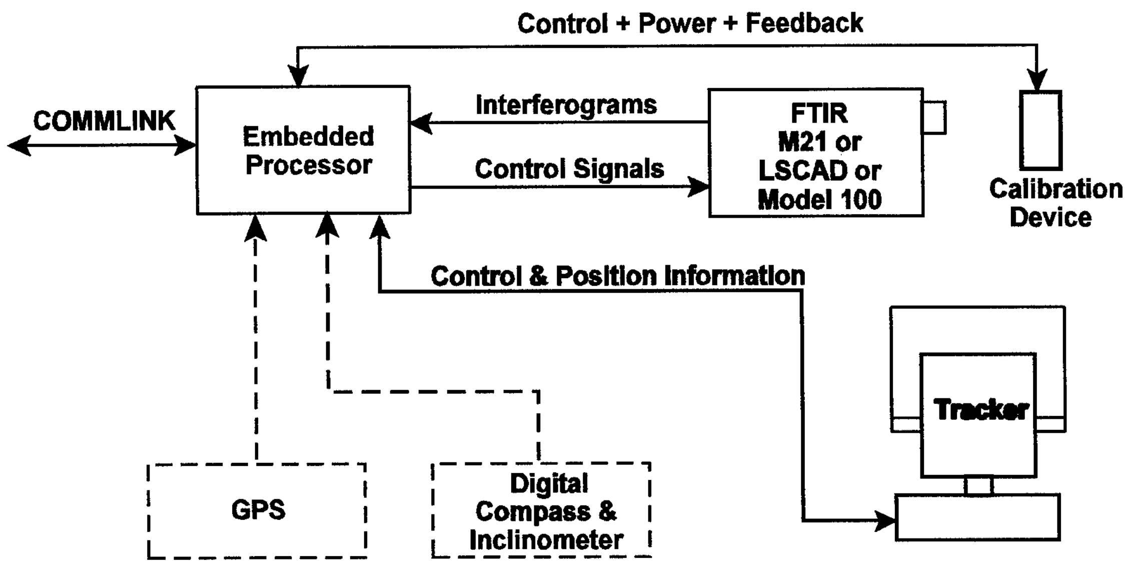

Figure 5 CSS Block Diagram.

- Rugged nonvolatile storage (probably FLASH disk)
- Printed circuit cards for control of calibration device (i.e., temperature sensor reading, ambient temperature reading, power control to thermo-electric (TE) module)

The control program that executes on the embedded processor performs the following tasks:

- Act upon any commands received from the MGS
- Collects interferograms from FTIR
- Schedules a calibration cycle periodically and stores calibration information
- Controls temperature of calibration device using a PID (proportional, integral, derivative) technique
- Sends commands to tracker to implement scan pattern
- Reads GPS position if the GPS is connected
- Reads compass and inclinometer if they are connected
- Performs steps necessary to interpret an interferogram and calculate the CL for a given chemical vapor. The steps include:
  - Fourier transform of igram with phase correction
  - detection of any chemicals present
  - conversion of spectra to radiometric units using stored calibration data
  - calculation of CL of chemicals present in radiometric spectra

- Send CL report to MGS
- Perform quality control

5.2.2 FTIR

The FTIR can be either of the following units:

5.2.2.1 M21

FTIR unit capable of 5 scans/second. Field rugged. Interface to this unit needs to be developed.

5.2.2.2 LSCAD

FTIR unit capable of higher speeds (as much as 40 scans/second). Also field rugged. MESH has built an interface to this FTIR.

5.2.2.3 Block M100

This FTIR is an updated version of the LSCAD and is commercially available. The interface is identical to the LSCAD interface.

5.2.3 Calibration Device

The calibration device is a blackbody with the following characteristics:

- Field rugged - operates from -20°C to 49°C
- Provides relative humidity measurement ± 5%
- Provides ambient temperature measurement ± 1°C
- Emissivity >90% from 800 to 1300 cm^{-1}
- Emissivity maximum to minimum <3% in 800 to 1300 cm^{-1} range
- Maximum temperature achievable is > ambient + 20°C
- Minimum temperature achievable is < ambient -15°C
- Temperature of surface in calm air (i.e., indoor) is stable to ± .25°C
- Accuracy of surface temperature is ± 1.0°C
- Some amount of shielding of surface from wind is desired
- Size of surface TBD. It will not be less than 2" square. It depends on how close the calibration device can be positioned to the front of the FTIR. The calibration device will be motorized so that is may be rapidly moved in and out of the FOV of the interferometer.

5.2.4 Tracker

The tracker will aim and point the FTIR unit. It has the following characteristics:

- Weight to be moved:
  depends on FTIR - M21 approx. 50 lbs.
  LSCAD approx. 10 lbs.
- Speed of movement: greater than 6 degrees per second at full load.
- Field rugged
- Azimuth drive
- Elevation drive is optional. Only required if vehicle mounted.

5.2.5 Digital Compass and Inclinometer (Optional)

This is needed if the CSS is vehicle mounted. It gives the actual heading and elevation of the FTIR. Not needed on a stationary unit since it will be leveled and aimed during set up.

5.2.6 GPS (Optional)

The GPS gives the location of the CSS. It is required if the CSS is vehicle mounted. It may be useful even in the stationary case as a convenient way to establish the CSS position when the CSS is set up.

5.3 Map Generator Subsystem (MGS)

This is the operator interface. It displays the cloud map in real time and archives all the data.

5.3.1 Tasks Performed by MGS

- Display map of cloud position either cloud edge or cloud concentration map.
- Archive data
- Interface with operator to configure the entire CTS. This will include:
  - scan patterns executed by CSS
  - accuracy in CL required of a CSS (adjustable by coadding)
- Communicate with the CSS units
- Run tomography algorithm when new information is available

5.3.2 MGS Hardware

The MGS hardware is to be a commercially available, field rugged portable computer, Pentium class, with a Windows OS.

- Hard drive storage better than 2 GB
- Graphics - SVGA or better
- Built-in pointing device
- Desirable to have a sunlight readable screen

5.4 Communication Link (COMMLINK)

The COMMLINK allows the flow of information to all the sensors in the CCTS from the MGS. Three technologies were considered to implement the COMMLINK on the test range: RS485, Ethernet on twisted pair, and Ethernet on fiber optic.

Table 4 Comparison of COMMLINK Technologies.

	RS485	Ethernet - wire	Ethernet - fiber
Number of Devices	32	256	256
Cable	2 wire	4 wire	fiber
Distance	4000'	300' from hub	50 km from hub
Distance with repeater	8000'	-	-
Network Topology	daisy chain	star	star
Cost	low	mid	high
Data Rate	19.2 KB	10/100 MB	10/100 MB

As shown in Table 4, the choice is not clear cut. The cost of cabling a large area is a major factor in the decision. Figure 6 shows that the problem with Ethernet is caused by its star topology. To cable a line of 3 sensors 300' apart would require 300 + 600 + 900 feet of fiber or 1800 feet. For the daisy chain, only 900 feet would be required to do the same job.

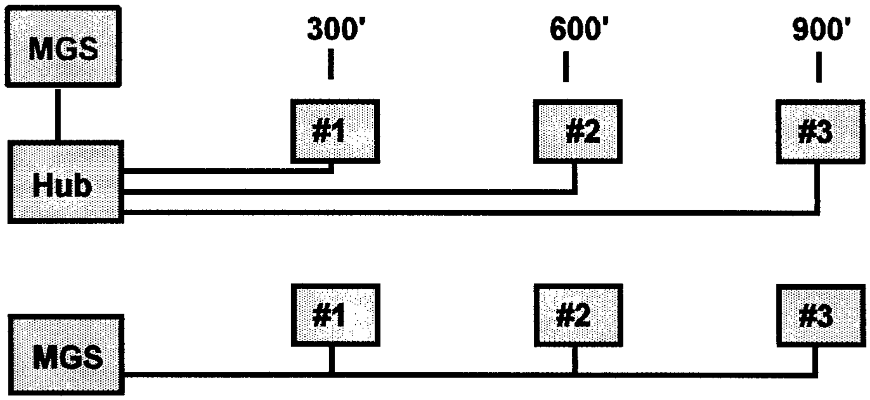

Figure 6 Star vs. Daisy Chain.

For 10 sensors in a line at 300' intervals with the hub at the center of the line would required 8850' of fiber versus only 2700' of cable for daisy chain. Therefore, RS485 was the only reasonable choice for the long distances expected. However, its limitation was the speed and supporting only 32 devices on one daisy chain. To overcome that limitation, a communication concentrator (COMMCONC) was used to augment the design. As shown in Figure 7, the MGS will only interface to 31 sensors or less. If more sensors are part of the CCTS, the one or more COMMCONCs will interface with the additional sensors. The MGS-COMMCONC link will be Ethernet to get the higher bandwidth needed to move all the concentrated data. The COMMCONCs will collocate with the MGS.

5.4.1 Direct Wire

Since RS485 is chosen, only 2 wires are needed (one twisted pair). However, the cable may also carry power to the sensors from the MGS location (see Power Section).

5.4.2 Radio Modems

This can be used where a CSS is on a vehicle and moving. It can also be used with fixed locations to eliminate the need to run wires long distances.

5.4.3 Interface to Other Instruments

As shown in Figure 7, incompatible instruments can be introduced to the CCTS by using an interface box. The interface box will handle the special interface requirements of the instrument they are hooked to . The IB will translate the data to a stream that will be readable by the MGS or a COMMCONC.

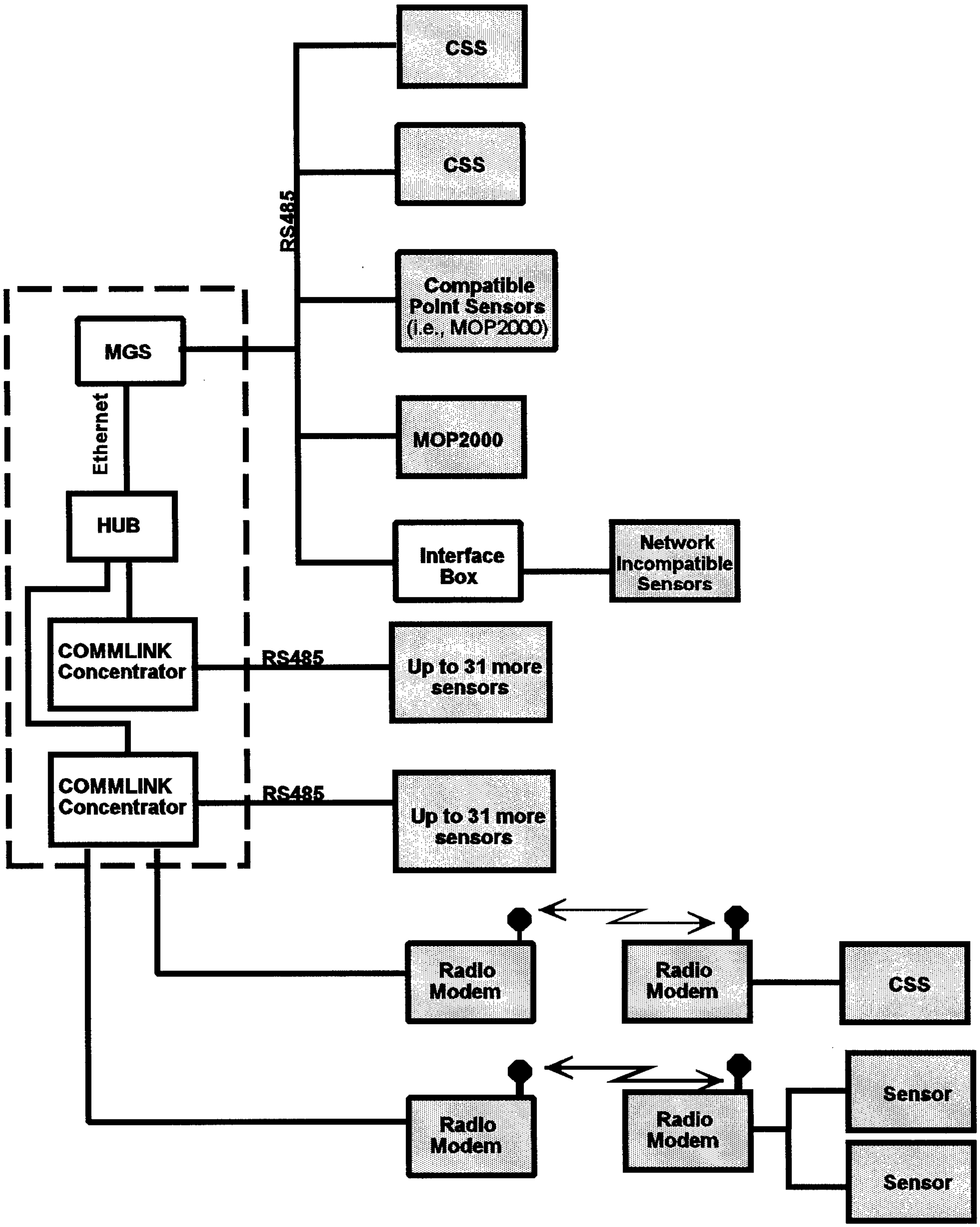

Figure 7 COMMLINK Implementation.

The IB is, in fact, very similar to a COMMCONC except that it may have serial ports or a parallel port dedicated to talking to the instrument. If the instrument produced a lot of data, the IB could hook into the Ethernet directly.

5.5 Other Instruments

The COMMLINK design allows other instruments to be included in the CCTS. The OTHER category can be either point sensors (IMS, GS, etc.) or standoff (LIDAR, IR camera, etc.). The MGS data fusion will accept either quantitative (concentration or concentration-pathlength) or qualitative (detections) measurements.

5.6 Power

There is no single answer to the issue of powering the CCTS components.

5.6.1 MGS Power

It is assumed that the MGS and any equipment collocated with it will be run on 110 VAC supplied either by utility or by a generator. Since there is only one MGS, this is a reasonable way to solve this problem and inexpensive. The collocated equipment would included COMMCONCs and may include OTHER instruments.

5.6.2 Range Power

For these instruments not collocated with the MGS, some other method of powering them is required since there may be a large number. For example, a grid of 10 by 10 point sensors is not unreasonable and 100 generators is out of the question.

The solution is to distribute power through the COMMLINK cables. The cable being run will be 6 wires with:

2 wires for the RS485 (small wire)
2 wires for the power (10 to 20 amp size wire)
1 wire for safety ground
1 wire for signal ground

The COMMCONCs will provide the power to the network.

The type of power that is distributed is an important safety consideration. Because of the inherent risks associated with 110 VAC power, it was decided not to use it even though it requires lower amperage and smaller wires. Instead, it was decided to follow the lead of the auto industry in powering the cars of the future.[1]

"The jump from 14 V to 42 V for system voltage may seem arbitrary, but it is the result of careful thought and years of work initiated by the MIT Consortium on Advanced Automotive Electrical/Electronic Systems and Components. The group eventually settled on 42 V as the optimum system voltage after considering safety constraints posed by global standards setting bodies, specifically a maximum voltage, including transient overvoltage, of 60 V dc."

The distributed voltage will be 42 V dc or 28 V dc. Certain legacy sensors may need 28 V dc, but the new sensors (CSS and MOP2000) will run on 42 V dc. By sizing the wires for 20 amps, almost 1 KW can be distributed or about 28 watts each to 30 sensors on one RS485 daisy chain. If a sensor needed 56 watts, then it would be 2 loads, and the number on that daisy chain would be reduced to 29 sensors.

5.6.3 Mobile Power

The mobile power units will get their power from the vehicle they are mounted on, either 28 V dc or 110 VAC.

6.0 ILSCAD

Table 5 shows a comparison that was done to aid in the decision to switch from the M21 to the ILSCAD in Phase II of the CCTS project. Table 6 shows the status and location of the 9 ILSCAD units that were produced by Block.

Table 5 Comparison.

	ILSCAD	M21
Weight	10 lbs.	50 lbs.
Size	Shoe box	Barbeque grill
Power	20 watt	?
Maintenance	Block Engineering	Unknown
Military Equipment	No	Type Classified
Manufactured	Yes - Model 100	No
Interface	Yes	No

Table 6 Status of ILSCADs.

Serial #	Status	Location as of 5/6/00
1	Broken	MESH
2	Working-used at CADDIE test 6/99	MESH
3	Refurbished by Intellitec, used at CADDIE test 6/99	Intellitec
4	Working - backup at CADDIE 6/99	MESH
5	Broken	MESH
6	Broken	MESH
7	Broken	MESH
8	Never completed - Unusable	JSLSCAD Team
10	Refurbished by Intellitec	Intellitec

7.0 PROPOSED IMPLEMENTATION - COTS VENDORS

In this section, the hardware and software vendors are selected for an implementation of the CCTS. This implementation was proposed for Phase II.

The approach used in building the CCTS is to use as much off-the-shelf hardware and software as possible. Table 7 lists the components used, the vendor who will supply them and whether they are off-the-shelf. All of the major components are off-the-shelf.

In Table 7, the following codes are used for part numbers:

1XXXX - used by CSS
2XXXX - used by MGS
3XXXX - used by COMMLINK
4XXXX - OTHER instrumentation
5XXXX - documentation
X9XXX - a software component

The CCTS will follow the design in Section 5 with two major enhancements:

- Point sensors will be included to demonstrate the versatility of the CCTS in accepting input from multiple types of sensors.
- In addition to cloud mapping, the map generator will be able to predict the future position of the cloud based on MET data.

The particular features of the CCTS to be delivered to Dugway are:

- The ILSCAD sensors which will be refurbished by Block Engineering.
- Three fixed location CSSs.
  Each CSS includes an azimuth only scanner, an FTIR enclosure and a tripod.
- One mobile CSS
  This includes an azimuth and elevation scanner, an FTIR enclosure, a digital compass, a GPS, a tripod and a radio modem.
- Five MOP2000 Chemical Point Sensors

Table 7 Component List for Dugway CCTS.

Part No.	Description	Quantity	Source	Off Shelf
10100	FTIRBOX-Fixed	3	MESH	Yes
10200	FTIRBOX- Mobile	1	MESH	Yes
11100	ILSCAD	4	JSLSCAD Team	Yes
12100	Scanner	1	Sagebrush	Yes
12200	Turntable	3	TBD	Yes
13100	Tripods	4	TBD	Yes
13200	Scanner/Tripod Brackets	4	MESH	No
13300	Generators	TBD	TBD	Yes
13400	Power Converter	TBD	TBD	Yes
19100	MCSS	4	MESH	Yes
19200	FTIR Radiometry	4	MESH	Yes
19300	Merging MCSS/ Radiometry	4	MESH	No
20100	Rugged Portable Computer	1	TBD	Yes
29100	DWARN	1	Litton/TASC	Yes
29200	Data Fusion	1	MESH	Yes
29300	Merging DWARN/ Data Fusion	1	MESH	No
29400	Communicate with All Sensors (CSS and Point)	1	MESH	No
30100	Radio Modems	2	TBD	Yes
30200	Cables	TBD	MESH	No
39100	Integrate Radio Modem into MCSS	1	MESH	No
40100	MOP2000	5	MESH	Yes

39100	Integrate Radio Modem into MCSS	1	MESH	No
49100	Integrate Point Sensor Type Data into Data Fusion	1	MESH	No
50100	Technical Description of CCTS	1	MESH	No
50200	Operator Manual	1	MESH	No

7.1 CSS

The Chemical Sensor Subsystem (see Section 5.2) is the FTIR sensor.

7.1.1 Packaging

The ILSCAD FTIR will be repackaged in a FTIRBOX, an off-the-shelf item designed for this purpose. See Figure 8 for a picture of the FTIRBOX mounted on a scanner. The features of the FTIRBOX are:

- Provides a calibration source (blackbody)
- EMI sealed enclosure
- Weather proof enclosure
- Internal heaters for cold weather operation (to -20 degrees C)
- Heat dissipation fins for hot weather operation (to 49 degrees C)
- Interface to any Block style FTIR included
- Pentium class computer for signal processing and running algorithms
- Communication with remote operator with either RS422/RS485 or Ethernet
- RS232 port to control a turntable or a azimuth/elevation scanner
- Mobile version includes a digital compass with inclinometer
- All versions include a GPS (useful to locate the fixed version)

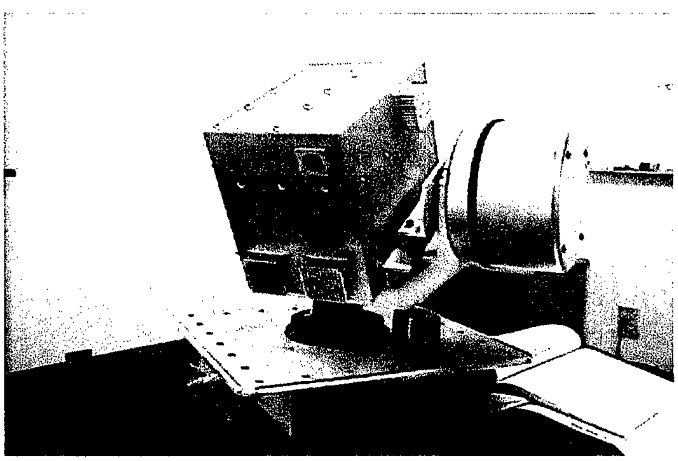

Figure 8 FTIRBOX Mounted on a Scanner.

Three of the FTIRBOXs will be the fixed version and one will be mobile. The fixed versions may be upgraded in the future to a mobile version.

7.1.2 ILSCAD

These FTIRs were obtained from the JSLSCAD team. The JSLSCAD team determined that with the eminent arrival of the JSLSCAD production model, they no longer needed the ILSCADs, which were research tools. Section 6 shows the status.

7.1.3 Refurbishment of ILSCADs

Of the eight ILSCADs, four will be put into working order. Units #3 and #10 were refurbished by Intellitec for their research on the JSLSCAD program. The other 6 units have not had any maintenance done for at least four years. The recommended service interval is 12 months.

The units will be refurbished by Block Engineering, Inc. of Marlboro, MA, the company that originally built the ILSCAD.

7.1.3.1 General Diagnostics and Adjustment

Block's general diagnostics on this type of instrument includes servo trimming, optical alignment, minor parts replacement if needed and additional adjustment of the unit to optimize its performance. If the optics are degraded, Block cannot guarantee return of the unit to its original NESR performance, but will recommend the steps which need to be taken to achieve this performance. An abbreviated Acceptance Test is performed at the conclusion of this work.

7.1.3.2 Laser Reference

The laser diodes installed in the ILSCAD units have been difficult to replace. Block has chosen to return to hardened He-Ne Laser references in the Model 100 Industrial/Commercial version of ILSCAD. Toward the end of the ILSCAD Program the laser diode Manufacturer was not able to guarantee units within the original purchase tolerances. Those purchase tolerances allowed Block to perform a final trim of wavelength and achieve stable operation by means of current and thermal tuning of the diode. Block does not recommend replacement of the laser diodes in those units which have faulty reference lasers due to the expense involved in restarting this procedure.

Retrofitting of the laser diode with a helium neon laser in a standard ILSCAD package is also problematical due to required changes and space constraints, and Block does not recommend it due to high cost/benefit ratio on an individual instrument basis.

7.1.3.3 Detector/Dewar/Cooler

The detector assemblies carry a one year warranty or 2000 hour estimated life on the cooler and a five year vacuum hold time on the dewar. There are several ways to proceed here.

1. Replacement of the entire assembly
2. Replacement of the cooler only
3. Refurbishment of the cooler

There are also other combinations such as refurbishment of a cooler and replacement of the detector/dewar, but the cost/benefit here is clearly not adequate for the limited additional life expectancy gained.

If the cooler no longer reaches temperature within the normal time tolerance, it needs to be refurbished or replaced. Refurbishment is less expensive, but only extends the life temporarily since the wear components are not changed. Only the Helium charge is replaced after an evacuation and multiple cycle gas cleanout. It can be a reasonable way to proceed if only limited extension of assembly life is needed, and the use history of the unit is known. Excessive noise or vibration in the cooler would indicate replacement as the wiser choice. If the unit cools down within specified tolerance, the cooler should probably be refurbished. If there is excessive cooldown time and the detector window is frosted, the dewar seal has been compromised and the detector/dewar need replacement. Unfortunately, this may also mask the need to replace the cooler which could also be at the end of its life.

Once it is de-integrated, the detector/dewar can be checked separately for liquid nitrogen hold time and independently confirm the seals are all still intact. Block has new fixturing which allows the checking of the detector/dewars alone.

Block will recommend the corrective action to be taken for each Detector/Dewar/Cooler assembly.

7.1.4 Scanner

The scanner is used to aim the FTIR and sweep it across the chemical cloud. The processor in the FTIRBOX controls the scan pattern. It can either be an operator supplied pattern or one that the FTIRBOX generates in its search for the chemical cloud. There are two types of scanners required, one for mobile operation and one for fixed operation.

For fixed, tripod mounted operation, only azimuth scanning is required as the FTIRBOX will be leveled when it is set up to give the plane necessary for scanning. However, a vehicle can have pitch and roll motion which must be canceled out. Therefore, the vehicle scanner must have both azimuth and elevation motors.

The vehicle scanner will be a Sagebrush scanner as shown in Figure 9. The vendor of the turntable scanner will be determined.

7.1.5 Choice of Scanner Type

In optical scanning of the nature needed by the CCTS, there are two ways to do the design:

a) Turn the entire instrument
b) Scan the optics only (beam steering)

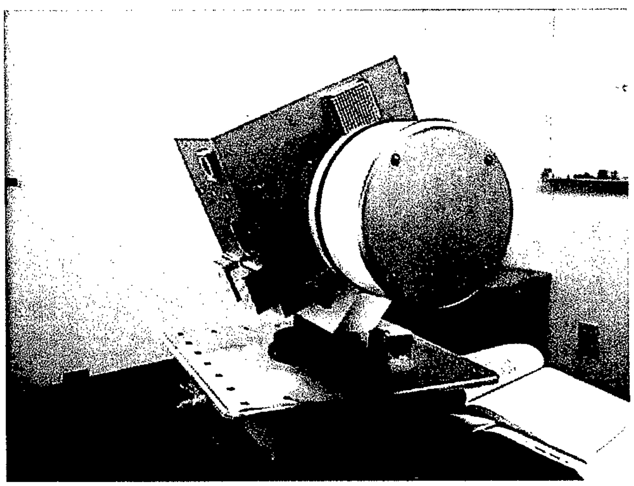

Figure 9 Sagebrush Scanner.

Scanning the optics is attractive because it is lightweight and operates at higher speeds than aiming an entire 25 lb. instrument. Only mirrors need to move. However, there are significant drawbacks. First, optical scanners are always custom design because the wave lengths of interest all require different lens and mirror types and the beam size has a significant impact on mirror size. The cost to custom design an optical scanner is typically above $1,000,000. The turntable or azimuth and elevation scanners are off-the-shelf and typically cost $5 - 20K.

The second and perhaps even more severe problem than the high price is that optical scanners have angular dependence. That is, the light that passes through the scanner is dependent on the direction that the scanner is pointed. There is a change in reflectivity of the mirrors for both an angular dependence and a wavelength dependence. The size of these changes is greater than can be tolerated in an instrument that is measuring ambient radiation because of the low levels of energy that ambient objects emit.

For these two reasons, MESH has chosen to aim the entire FTIR instead of beam steering.

7.1.6 CSS Software

The software running in the CSS processor has two primary functions; control of the CSS and analysis of the FTIR data. MESH has two products that perform these tasks. MCSS (MESH Chemical Sensing Software) is designed to run in the FTIRBOX and does everything listed in the design (Section 4.2.1). However, MCSS only does chemical detection, not quantitative analysis. MESH's FTIR Radiometry Software does quantitative analysis and gives the results in either ppm-m or mg/m^2. The two separate packages would need to be merged together into a single program to run inside the FTIRBOX.

7.1.7 Miscellaneous CSS Hardware

7.1.7.1 Stand

Each of the CSS units will mount on a tripod for use in the field. The tripods will have the adjustments necessary to level the CSS in the field. To attach the scanner to the tripod, a custom bracket may be necessary.

7.1.7.2 Power

The units in the field need to be supplied with power. Whether this is accomplished with a generator for the CSS or whether utility power is available needs to be decided.

7.2 MGS

The data from all the sensors is algebraically combined on the Map Generator Subsystem (MGS). Also, all display and mapping is performed here. Finally, all operator commands for CCTS reconfiguration are entered.

7.2.1 Rugged Field Computer

The MGS will be implemented on a commercially available rugged portable computer. Because the primary function of the MGS is display, this computer should have a screen resolution of SVGA or better. The operating system will be Windows based.

7.2.2 MGS Software

The data fusion function is performed by the MESH Tomographic Software Package. The mapping is accomplished by the Litton/TASC DWARN product. These two packages need to be merged together such that the cloud footprint produced by the data fusion is compatible with DWARN.

DWARN will add cloud movement prediction to CCTS. DWARN accepts cloud footprints from two plume models (SCIPUFF, a DOD model and Aloha, a FEMA model). MESH will add their cloud map in a manner similar to the way SCIPUFF and Aloha are incorporated.

7.2.3 Control of Sensor Array From MGS

The operator must be able to control the sensor array via the COMMLINK. Also, MGS must collect sensor readings continuously. MESH currently has a DOS based program that does this. This function will be rewritten under Windows.

7.3 COMMLINK

The CCTS configuration will include one mobile CSS. The other three CSSs and all five point sensors will be direct wire connection. The fixed sensors can be upgraded in the future if desired.

7.3.1 Radio Modems

This activity is covered under the optional task.

7.3.2 Direct Wire

All other sensors are direct wire. The cables for these are custom made to the required length.

7.4 Point Sensor

To show that the CCTS can handle data of various types, five point sensors are added to the four standoff sensors in the sensor array.

7.4.1 MOP2000

This point sensor was chosen for several reasons. First, since it is optical based, it can sense any chemical that the FTIRs can sense. Second, it is manufactured by MESH and any interface problems can be easily resolved as compared with dealing with a company that has proprietary interface information. The MOP2000 was designed from the ground up to be part of a sensor array, so no interface problems are expected. Third, it is low cost.

7.4.2 Point Sensor Software

The Data Fusion currently only supports standoff sensors. The point sensor concept would need to be added to the tomography software.

7.5 Documentation

MESH will provide the following documentation:

7.5.1 Technical Description of CCTS

Complete documentation including a parts list and cable interface descriptions. Also, MESH will provide a description of the functioning of the entire system. As a large percentage of the system content is off-the-shelf, it is anticipated that much of this will be in the form of catalogs and manuals from the equipment/software vendors.

7.5.2 Operator Manual

MESH will provide a complete set of instructions for the operator. As much as possible, the instructions will be on-line in the MGS system.

8.0 CCTS PLANNING TOOL

The CCTS Planning Tool (CCTSPLAN) is software that allows the test engineer to experiment with a different number of sensors and sensor placement to see its effect on the cloud map. This effort has been started in Phase I. It will be completed in Phase II. Note that this ties in very closely with the display from DWARN and the Planning Tool may be moved into DWARN in Phase II.

In Phase I, CCTSPLAN has been implemented under Windows using Visual Basic. This section will show the steps required to place standoff sensors, point sensors, and the UUT on the map. Other parameters that need to be set are wind speed, wind direction, sensor speed, etc.

8.1 Operator Guide to CCTS Plan

The following steps are necessary to generate the plume.

8.1.1 Place Release Location and UUT

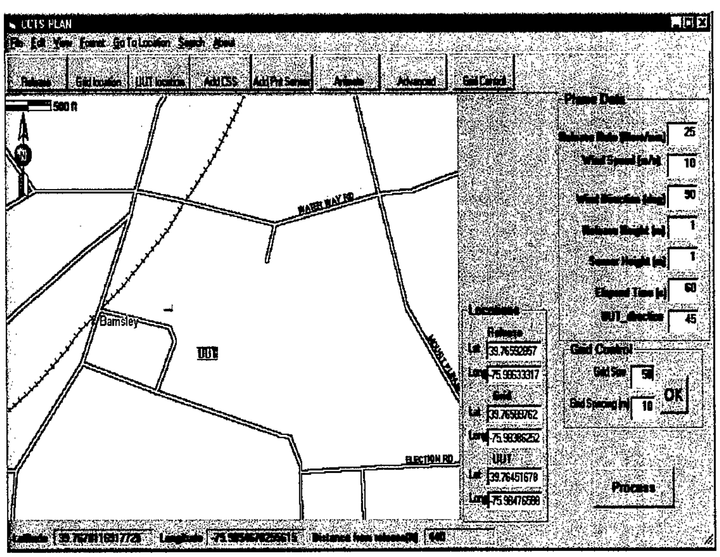

Figure 10 Placement of Release and UUT.

Select the release location by clicking on the "Release" button and moving the mouse cursor to the desired location on the map. Place a release location marker by left clicking on the map. Select a location for the UUT and the plume grid with the "Grid location" and "UUT location" buttons in the same manner. When locating the plume grid, select a location near the Release location. The latitude and longitude coordinates for these locations will be displayed in the "Locations" window as shown in Figure 10.

8.1.2 Place Point Sensor and CSS

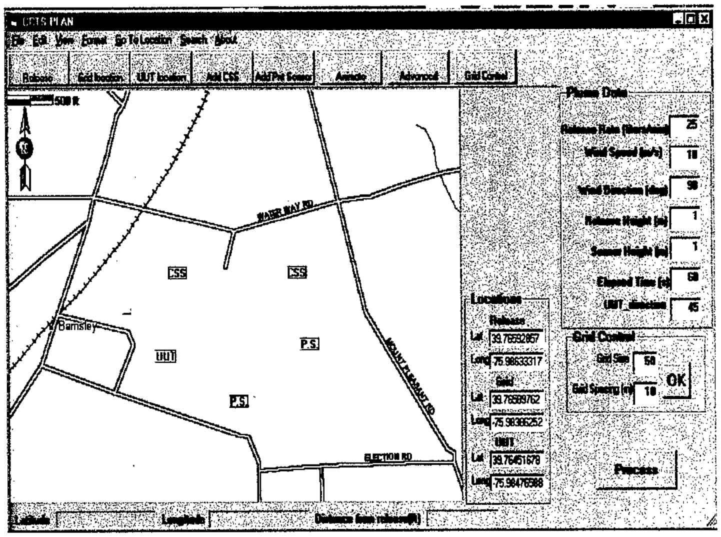

Figure 11 Placement of CSS and Point Sensors.

Point Sensors and CSS's may be added to the map using the "Add CSS" and "Add Pnt Sensor" buttons by following the steps described in Section 8.1, as shown in Figure 11.

8.1.3 Plume Parameters

To modify the "Plume Data" settings select the value to be changed and enter a new value. New settings can be used for each run to examine the effects of different values on the plume. The 'Plume Grid' settings can be changed by selecting the "Grid Control" button at the top. This will determine the size of the area to be examined as shown in Figure 11.

8.1.4 Process Data

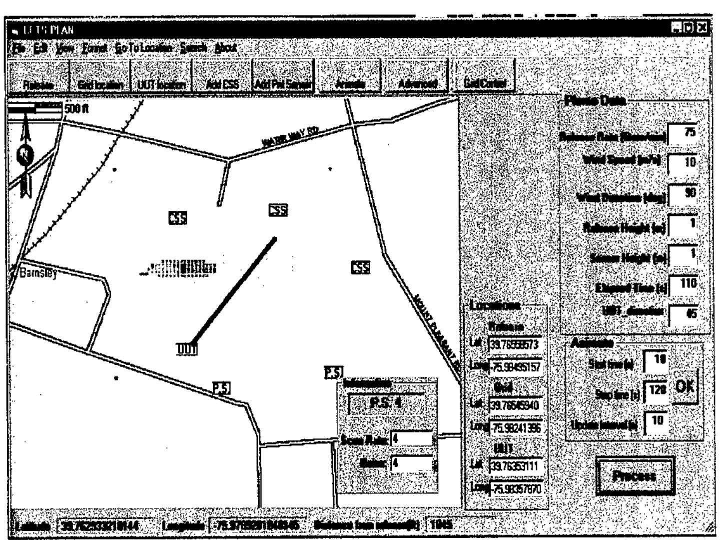

Figure 12 Generated Plume.

After all objects have been placed on the map and the plume parameters have been set, the new plume position can be calculated by clicking the "Process" button. The program will then calculate the location and concentration of the new plume and display it in the window. The center line of the UUT will be displayed as a black line in the direction of focus. The noise and scan rate values of each CSS and point sensor can be viewed by right clicking on the desired unit as shown in Figure 12.

8.1.5 Animate Data

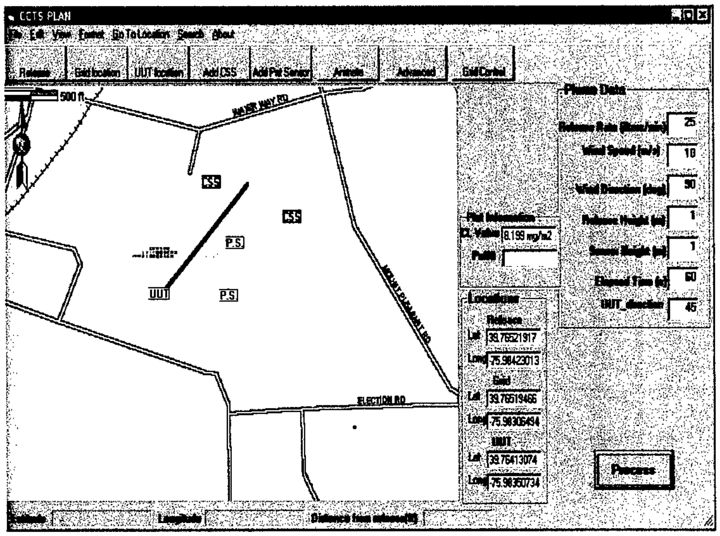

Figure 13 Animated Plume.

The chemical cloud can be animated to show the cloud at different time periods. Access the animation control with the "Animate" button at the top of the screen. The start time, stop time and Update interval for the animation can be modified from the "Animate" window. To start the animation, click "OK" in the animation window. The calculation for each time period will take place and the new chemical cloud will be displayed as shown in Figure 13.

8.1.6 Measured CL

The measured CL for the UUT will be displayed in the "Plot Information" window after the Plume data has been processed as shown in Figure 13.

8.1.7 Modify Settings

After data has been plotted, parameters may be modified and the plume recalculated by clicking on the "Process" button.

9.0 PHASE I CONTRACT DELIVERABLES

The contract compliance matrix is shown in Table 8a. Tasks 1 thru 9 are deliverables under the Phase I contract. In Table 8b, Tasks 10 thru 15 are from the optional phase and were included because three of the optional tasks were also completed under the Phase I contract.

Table 8a Contract Compliance Matrix - Phase I.

Task #	Topic	How Met	Reference in this Report
1	Actual Cloud Map	CCTS Plan	Section 8.1.5
2	Actual CL	CCTS Plan	Section 8.1.6
3	Measured CL	CCTS Plan	Section 8.1.6
4	Predicted Cloud Map	CCTS Plan	Section 8.1.5
5	Number and Position of Vantage Points	CCTS Plan	Sections 8.1.1 and 8.1.2
6	Time Invariant Instrument Scan Speed	CCTS Plan	Section 8.1.4
7	CTS Accuracy Requirements	Requirements	Section 4
8	CTS Hardware Detailed Design	Detailed Design	Section 5
9	Build M21 Interface	Deleted by Army, Replaced by COTS Interface	Sections 2.1 and 7.111

Table 8b Extra Tasks - Optional Phase.

Task #	Topic	How Met	Reference in this Report
10	Design and Build Bracket for M21	Deleted by Army	Section 2.1
11	Build M21 Calibration Device	Commercially Available	Section 7.1.1
12	Integrate Radio Modems	Open	
13	Integrate GPS	Open	
14	Select Mapping System	DWARN	Section 7.2.2
15	Select Archive Protocol	Open	

10.0 REFERENCES

1. J.G. Kasasskian, J.M. Miller, N. Traub, *"Automotive Electronics Power Up"*, IEEE Spectrum, May 2000.

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13. ABSTRACT (Maximum 200 words)
Report developed under SBIR contract for topic A99-167. The Chemical Cloud Tracking System (CTTS) will allow tracking the movement of chemical clouds in real time from a safe standoff distance. The instruments used are passive standoff chemical agent detectors already fielded. Each instrument individually can only measure the total of all the chemical in its line-of-site; the distance to the cloud is unknown. By merging data from multiple vantage points (either one instrument moving past the cloud or two or more instruments spaced so as to view the cloud from different directions) a map of the cloud location can be generated. The equipment required for the proposed system is either government-off-the-shelf or commercially available. Also, the data fusion techniques (tomography) have been demonstrated previously in the medical field. The data fusion techniques will also accept point detector readings.

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