INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0391

Heat Stress Monitoring System

Deactivation and Decommissioning Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

Heat Stress Monitoring System

OST Reference #1953

Deactivation and Decommissioning Focus Area

Demonstrated at
Hanford Site
Richland, Washington

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Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://OST.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

The MiniMitter VitalSense Telemetry System's heat stress monitoring system (HSMS) is designed to monitor the vital signs of individual workers as they perform work in conditions that might be conducive to heat exhaustion or heat stress. The HSMS provides real-time data on the physiological condition of workers which can be monitored to prevent heat stress or other adverse health situations. This system is particularly useful when workers are wearing personal protective clothing or respirators that make visual observation of their condition more difficult. The MiniMitter VitalSense Telemetry System can monitor up to four channels (e.g., heart rate, body activity, ear canal, and skin temperature) and ten workers from a single supervisory station. The monitors are interfaced with a portable computer that updates and records information on individual workers. This innovative technology, even though it costs more, is an attractive alternative to the traditional (baseline) technology, which measures environmental statistics and predicts the average worker's reaction to those environmental conditions without taking the physical condition of the individual worker into consideration. Although use of the improved technology might be justified purely on the basis of improved safety, it has the potential to pay for itself by reducing worker time lost caused by heat stress incidents.

■ Technology Summary

The MiniMitter VitalSense telemetry system can provide real-time monitoring of vital signs of up to ten workers per station. It consists of a series of probes worn by the worker, a portable monitor, a monitoring system that utilizes wireless signal transmissions, and a personal computer (PC). The signals from a worker are transmitted in 3 seconds; with ten workers their vital senses are scanned every 30 seconds. The computer collects and logs data from individual workers that can be used to develop a health profile for individuals. The computer also updates the vital signs of the worker, allowing proactive decisions to be made about whether to modify worker activity to avoid heat stress situations.

Ear Temperature Probe

Problem Addressed

The U.S. Department of Energy's (DOE) nuclear facility decontamination and decommissioning (D&D) program involves the need to decontaminate and decommission buildings expeditiously and cost-effectively. Simultaneously, the health and safety of personnel involved in the D&D activities is of primary concern. Often, D&D workers must perform duties in inclement weather, and because they also frequently work in contaminated areas, they must wear personal protective clothing and/or respirators. Monitoring the health status of workers under these conditions is an important component of ensuring their safety. The improved system monitors body temperature, heart rate, and motion activities of individual workers remotely and records the associated data in real time on a PC. The traditional (baseline) method--wet bulb globe thermometer (WBGT), along with heat stress training provided to employees--does not measure health statistics of individual workers, rather the environment in which work is being performed. The baseline is therefore less reliable in predicting the specific needs of individual workers.

Features and Components

The improved system is characterized by the following features:

- Real-time monitoring to prevent potential heat stress or other adverse health situations.
- Monitors up to four channels (heart rate, body activity, and skin and ear canal temperature) for up to ten employees from a single supervisory station.

- Ability to preset each monitoring channel and alarm warnings for specific physical conditions and characteristics of individual employees.

- Ability to warn workers of potential dangers in two ways: automatic signal from the computer to a light-emitting diode warning device mounted near the worker's eyes, or a manual alarm controlled at the supervisory station.

- Automatic, rapid update and recording of information into the computer from each individual being monitored, with wireless signal transmission over 300 m (1,000 ft).

- Equipment costs $3,600 for the base station and software, plus $3,500 per sensing/transmitting set, with rental options available at 10% of purchase price per month.

The system consists of the following components:

- A series of temperature, heart rate, and body activity probes and a monitor/transmitter weighing less than 0.5 kg (1 lb) that are worn by each worker.

- A rechargeable battery for each monitor that retains its operating charge for at least 8 hours of continuous use, and an AC-powered receiver and computer at the supervisory station.

- An IBM-compatible PC to monitor personnel, and collect and record the data generated by probes.

- A wireless monitoring system that utilizes spread spectrum technology that automatically uses the clearest frequency, provides security against unauthorized access to health data, and is not regulated by the Federal Communications Commission (FCC).

Potential Markets/Applicability

The MiniMitter VitalSense telemetry system represents an improved technology that can be used wherever workers could be potentially exposed to heat exhaustion or heat stress. The system is particularly useful when work must be performed in high ambient temperatures or when personal protective clothing or respirators must be worn. The system has applicability at both DOE and other federal sites, as well as at commercial facilities, and can be used both inside and outdoors. This technology is well suited for on-line heat stress monitoring (increases the chance of detecting a heat stress situation).

Advantages of the Innovative Technology

- Provides real-time physiological monitoring and logged the data automatically in the computer database for future use.

- Establishes databases for individual employees with alarm set points specific to the employee, depending on the individual's physical condition and abilities.

- Capability to provide information that can be used to adjust worker stay time, which could contribute to increased productivity.

- When located in close proximity, the wireless system experiences minor interference with other equipment.

The following table summarizes a comparison of the improved system and the baseline, a combination of WBGT and heat stress training provided to employees, against key criteria.

Category	Comments/HSMS Compared to Baseline
Cost	Higher than baseline, but health and safety benefits should be considered; has potential to pay for itself by reducing worker time lost caused by heat stress incidents
Performance	Better than the baseline; can provide real-time monitoring of vital signs of individual workers
Implementation	No special site services required for implementing this tool
Secondary Waste Generation	Does not generate secondary waste
Safety	Use of this tool increases safety, significantly reducing the likelihood of worker heat stress compared to baseline
Ease of use	Easy to use, short learning curve

Operator Concerns

Although the transmitter and receiver units have been modified for rugged conditions, the units must be handled with care. In addition, the operator and user should take all usual safety precautions prior to operating the system. Also, if this system is used in radiologically contaminated areas, proper radiological work practices and engineering controls should be taken to prevent personnel or any system components from becoming contaminated.

Skills/Training

Required training for D&D workers is minimal. Workers need to learn how to use the probes and how to properly install them on themselves. Setting up and operating the system properly requires approximately 1 hour of instruction.

Demonstration Summary

This report covers the period July through September 1997, during which Bechtel Hanford, Inc. (BHI), the DOE, Richland Operations Office (RL) Environmental Restoration Contractor, demonstrated the system. Both the improved and baseline technologies were examined and compared under controlled conditions at the C Reactor at the Hanford Site.

Demonstration Site Description

At its former weapons production sites, the DOE is conducting an evaluation of improved technologies that might prove valuable for facility D&D. As part of the Hanford Site Large-Scale Demonstration and Deployment Project (LSDDP) at the C Reactor Interim Safe Storage (ISS) Project, 20 technologies have been demonstrated and assessed against baseline technologies currently in use. DOE's Office of Science & Technology/Deactivation and Decommissioning Focus Area, in collaboration with the Environmental Restoration Program, is undertaking a major effort of demonstrating improved and innovative technologies at its sites nationwide. If successfully demonstrated at the Hanford Site, these innovative technologies could be implemented at other DOE sites and similar government or commercial facilities. The documentation at the C Reactor Complex was conducted while workers were performing various D&D activities, some dressed in full PPE with respirator, indoors and outdoors, and when ambient temperature exceeded 27°C (80°F).

Regulatory Issues

The system monitors vital body signs, such as body temperature and heart rate, and there are no special regulatory permits required for its operation and use. The wireless transmission system does not require FCC licensing. This system can be used within the requirements of 10 *Code of Federal Regulations* (CFR), Parts 20 and 835, and proposed Part 834 for radiological protection of workers and the environment, and Occupational Safety and Health Administration (OSHA) guidelines (29 CFR).

Technology Availability

The technology demonstrated at the Hanford Site's C Reactor was the first such demonstration at a DOE site. The system used at C Reactor was the first production unit. Since its demonstration at the C Reactor, MiniMitter has initiated a mass production mode for the system, and it is available off-the-shelf. In addition, since the demonstration at Hanford Site's C Reactor, there have been many requests to demonstrate the system at private sites.

Technology Limitations/Needs for Future Development

The transmission signal has some limitations, and the base station location should be tested when being used in areas with thick concrete or steel obstructions. (The range can be readily improved by using either a taller antenna or moving the antenna closer to the monitors with a coaxial cable connection to the base station.) Except for the carrying pouch, the demonstration at the C Reactor indicated no need to modify features of the system.

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Others
All published Innovative Technology Summary Reports are available at http://em-50.em.doe.gov. The Technology Management System, also available through the EM50 Web site, provides information about OST programs, technologies, and problems. The OST Reference Number for Heat Stress Monitoring System (HSMS) is 1953.

SECTION 2

TECHNOLOGY DESCRIPTION

■ Overall Technology/Process Definition

The heat stress monitoring system (HSMS) is a series of probes, a monitor, and a PC that measures vital signs of D&D workers while they are performing work activities. From the supervisory station, as many as ten workers can be monitored simultaneously. The real-time data can be used to instantaneously detect potential problems and adjust work activities accordingly to protect worker safety and ensure optimal productivity.

The HSMS consists of a small plastic case to enclose the electronics and wireless radio components; a laptop computer and software; a rechargeable battery supply; and a series of temperature, heart rate, and body activity probes, which are worn by the worker (Figure 1). Body temperature is sensed in the ear. Skin temperature is sensed with a taped-on probe. Heart rate is monitored with a chest band. Motion is sensed with a mercury switch in the transceiver.
The wearable monitor weighs less than 0.5 kg (1 lb.) and is 15.5 cm by 9 cm, with a thickness of 3.5 to 4.5 cm.

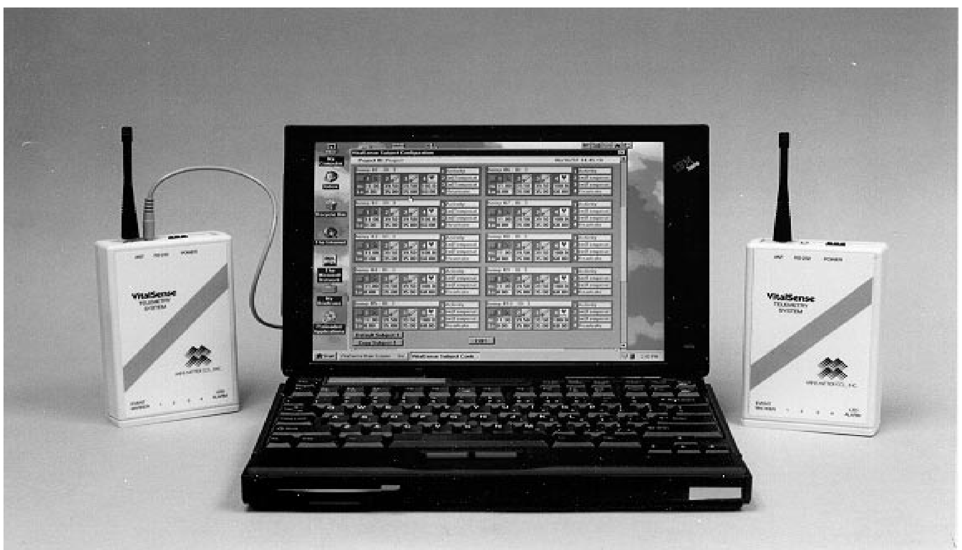

Figure 1. Laptop PC and transceivers with probes attached.

In this demonstration, the unit was able to directly monitor up to four channels (heart rate, body activity, and skin and ear canal temperature data). Each monitoring channel on this system can be preset to trigger an alarm set point. The unit has been designed so that, in the future, it can accommodate additional channels for either more physiological signals or for monitoring external sensors such as radiation, toxic chemicals, or noise.

As many as ten workers can be monitored in series by a single supervisory station. The data from an individual worker are transmitted in 3 seconds. With ten workers, every 30 seconds the information from one individual is automatically updated and recorded by the computer in a sequential fashion. If incipient heat stress or high heart rate is detected, the system will automatically activate the light-emitting diode warning device mounted near the worker’s eyes per the set parameters. Alternatively, the worker manning the supervisory station can manually alarm a person. After receiving the warning, the worker can withdraw from the work area and consult with the supervisor. If communication is lost, is out of range, or if there is transmission interference, the diode alerts the worker.

Another key innovation of this monitoring system is its wireless capability. Utilizing spread spectrum technology, signals can be transmitted over 300 m (1,000 ft). The power is 1 watt, with a frequency range from 902 to 928 megahertz (MHz). The system automatically selects the frequency that provides the clearest transmission of signals. Unauthorized persons cannot readily decode the data being transmitted. The system meets the requirements of FCC Part 15 and requires no licensing.

This system is battery operated, and the rechargeable battery supply will retain its operating charge for at least 8 hours of continuous use.

VitalSense software is IBM-PC Windows™ compatible, and data are collected in ASCII format. Conversion of the data is easily completed in Excel™ and charts can be printed for further comparison. Downloading the logged data requires basic computer skills. Also, the data can be manipulated for graphs and other presentation material.

System Operation

For the purposes of the demonstration at the C Reactor, the system was set up and operated as follows:

- Start the computer and run the MiniMitter software (the software is Windows driven)
- Check the computer and software setting for operation
- Connect the receiver station to the computer through com port 1 (an RS 232 connection)
- Connect all probes (up to four probes per transceiver) to the transceiver units (carried by workers along with the probes)
- Assign each transceiver probe to personnel via the software (up to ten)
- Setup the probes alarm setting parameters for each transceiver (each person)
- Attach the probes and the transceiver to the personnel using the carrying case and the provided belts
- Check to see that the probes are operational and produce reasonable results (system is functioning)
- Save the setting and the configuration for the monitoring occurring at the time
- Start the system when the work begins
- Save the data onto the hard disk or a floppy diskette
- Stop the software at the end of the monitoring session.

™Windows and Excel are trademarks of Microsoft Corporation.

SECTION 3

PERFORMANCE

■ Demonstration Plan

Site Description

The demonstration was conducted at the DOE's Hanford Site by site personnel. BHI is the DOE Richland Operations Office's Environmental Restoration Contractor and is responsible for the D&D program at the Hanford Site. The purpose of the demonstration is to comprehensively evaluate the cost and performance of commercially-available and newly-developed technologies to place Hanford's C Reactor into an interim storage mode for up to 75 years, or until the final disposal of the reactor's core is completed. The C Reactor ISS objectives include placing the reactor in a condition that will not preclude or increase future decommissioning costs, minimizing the potential for releases to the environment, and reducing the frequency of inspections thereby reducing potential risk to workers.

The ER Contractor developed a specific instruction for completing this demonstration at the Hanford Site for the LSTD Project. The instruction was carried out at the C Reactor to perform the heat stress monitoring. The demonstration occurred at a variety of locations at the C Reactor during July through September 1997. The work was performed by D&D workers, while a MiniMitter representative was present at the site for a period of 8 days (3 days at the beginning of the demonstration in July and 5 days during August) to assist with the demonstration, and to serve in an advisory and instructional capacity for proper operation of the system.

The work activities performed during the demonstration at the C Reactor included radiological surveying inside an enclosed, unventilated, concrete exhaust fan plenum; heavy equipment removal; light equipment removal; and painting. All of these jobs were labor-intensive and required the use of one or two sets of disposable protective coveralls. Several tasks also required the use of respirators. Use of personal protective clothing inhibits the body's natural cooling mechanism by preventing evaporation of perspiration. Use of respirators generally increases the workload on the body and thereby creates increased body temperature. The outdoor temperature at the Hanford Site during the summer months, when the demonstration was conducted, can reach in excess of 100° F. These conditions can increase the potential adverse impacts on worker health, increasing the importance of closely monitoring worker vital signs.

Performance Objectives

The objective of this technology demonstration was to assess the following features of the heat stress monitoring system:

- Capacity to collect several human vital signs simultaneously
- Ability to provide real-time personnel monitoring
- Accuracy with which human vital signs are recorded
- Ability to transmit the remotely collected data to a command station
- Ability to transmit data through structures and building materials
- Capacity to record human vital signs in magnetic storage media.

Demonstration Chronology

Pre-/Post-Monitoring Checks

- The HSMS probes and transceiver was checked for operation by D&D personnel before and after the demonstration.
- The HSMS probes were checked before and after demonstration to check for signs of wear or damage.

Innovative Technology

Parameters were set on the four channels (heart rate, body activity, ear canal temperature, and skin temperature) of the VitalSense. Skin temperature was monitored in two separate areas: the navel and under the arm. Experimentation with the naval temperature method proved to be difficult and inaccurate, and was therefore discontinued after the first day of the demonstration. The under-arm skin temperature was reliable and was used for the remainder of the testing (Figures 2, 3, and 4).

Figure 2. Ear temp. probe as installed in the ear.

Figure 3. Naval & skin temp. and heart rate probes as installed.

Figure 4. Heart rate probe and its belt.

The alarm set points were set as follows (as per instruction of the project safety and industrial hygiene representative) with three workers being monitored simultaneously:

Heart rate	(185 - 0.65 * Age) bpm, not to exceed 180 bpm
Skin temperature	38.5°C (101.3°F)
Ear temperature	38.5°C (101.3°F)
Activity rate	30 movements/scan

Environmental WBGT temperatures ranged from 17.8°C (64°F) to 23.3°C (74°F). The WBGT for a 75/25 work/rest regimen was established at 25.6°C (78°F) by the project safety and industrial hygiene representative.

The supervisory station was set up approximately 30 m (100 ft) away from workers. The telemetry system was able to travel the distance through 45 cm (18 in.) of concrete and steel plating.

Monitoring with HSMS

For this technology demonstration, the HSMS was used to monitor workers who were to cut pipes and conduit inside and outside of the C Reactor. The results of this innovative technology demonstration are as follows:

- Eight workers were randomly selected that would be working in potential heat stress environment during 14 monitoring events in July 1997. Ten additional workers were monitored during August and September 1997, for 20 additional monitoring events. Due to the summer being unexpectedly colder than normal, the number of events that might have required heat stress monitoring was reduced.

- During this demonstration, high alarms were set off 14 times for heart rate and more than 50 times for activity level. During events in which heart rates were elevated for more than 18 seconds and monitored activity was at a high sustained level, the Safety and Health representative spoke with workers and had them modify work activities to lower their heart rate, which was successful.

- In addition to personnel monitoring, a series of laboratory evaluations using HSMS temperature probes was conducted to assess the reliability of the probes and communication system (data collection and transmission system). Using a water bath, initial comparisons between temperature thermistor readings and digital thermometer readings were made. A total of nine readings were taken. The readings showed a gradual drop in temperature as the water bath cooled. The readings are presented in Table 1.

Table 1. Innovative technology thermistor temperature recording accuracy

Time	HSMS Thermistor	Thermometer	% Diff
14:20:07	38.0°C (100.36°F)	38.0°C (100.4°F)	(0.040)
14:20:52	37.6°C (99.64°F)	37.7°C (99.8°F)	(0.160)
14:21:37	37.2°C (98.94°F)	37.4°C (99.3°F)	(0.363)
14:22:35	36.8°C (98.26°F)	37.1°C (98.8°F)	(0.547)
14:23:28	36.8°C (98.26°F)	36.8°C (98.3°F)	(0.041)
14:24:14	36.3°C (97.27°F)	36.6°C (97.8°F)	(0.542)
14:25:53	36.0°C (96.87°F)	36.1°C (97.0°F)	(0.134)
14:27:06	35.7°C (96.19°F)	35.9°C (96.6°F)	(0.424)

- Preliminary results showed an acceptable deviation between the thermistor and the thermometer. More evaluations of temperature variance will be conducted.

- Three C Reactor technology demonstration group members' heart rates were monitored by this HSMS and, periodically, each member measured his/her wrist pulse rate and compared it to the HSMS reading at the time. Each time, the heart rate reported by the HSMS differed by 2 to 5 pulses.

- A range assessment was performed to determine the range within which data from the test subjects could be transmitted to the supervisor station. The range seems rather extensive in a line-of-sight measurement. A minimum distance of 300 m (1,000 ft) (line of sight) is achievable. However, with the presence of obstructions and interferences, transmission was limited. To check this, a transmitter was carried by personnel inside a vehicle and the signal at the receiver was monitored. A cellular phone was carried by the personnel inside the vehicle so that communication about the signal could take place. As the vehicle carrying the transmitter moved away from the receiver, the signal was lost. After the vehicle was turned around and moved back toward the receiver, the signal was not reestablished until nearly the point of origin. It is possible that the cellular phone frequency could have caused interference, obliterating the signal to the receiver.

- MiniMitter furnished five HSMS monitors onsite for potential use during the demonstration. Interference evaluations were performed on each of the five HSMS monitors. Although no personnel were monitored during this interference test, transmission signals from each of the five HSMS was detected. The transmitters were placed as follows:

  Unit #1: Placed in farthest room of the conference trailer. The unit was approximately 85 yards from the receiver. Five trailers were in line with the signal. The transmitter was in the proximity of two personnel who were working with computers. The signal lock was intermittent.

  Unit #2: Placed by the computer in the closest room of the conference trailer. The unit was approximately 75 yards from the receiver. The signal lock was appreciatively more stable. Some loss still occurred. About four and a half trailers were in line with the signal.

  Unit #3: Placed inside the Site Safety Representative and Rad Con supervisor's office in the engineering office trailer. The unit was approximately 65 yards from the receiver. The signal lock was very good; however, loss still occurred. Three trailers were in line with the signal.

  Unit #4: Placed in the copy room of the engineering office trailer. The unit was, again, approximately 65 yards from the receiver. The signal lock still good. Slightly higher loss occurred than the Site Safety office. Three trailers were in line with the signal.

  Unit #5: Placed in the instrument storage room of the radiological control technician trailer. The unit was approximately 23 yards from the receiver. The signal lock for this test was the best of the five. Slight loss still occurred. One trailer was in line with the signal.

- The receiver itself was placed in the first lunchroom trailer at C Reactor, which is in proximity to two other trailers (restrooms and change room trailers). The battery charge on all five transmitters was above 12 volts for the entire test time. The total run time for the test was 126 minutes.

The results of the assessment are shown in Table 2. The loss rate shown for unit #1 is not desirable. However, the signal strength could be increased by use of a longer antenna or installing a signal booster (a secondary antenna).

Table 2. HSMS transceiver units signal transmission evaluation

Unit #	Samples collected	Number of times the signal was lost	Percentage of signal loss
1	507	272	54%
2	508	89	18%
3	508	17	3%
4	507	47	9%
5	507	8	2%

- Interference testing with RadCon instrumentation was also performed. There was no significant effect on the HSMS resulting from RadCon instrumentation (one instance of interference was noted when a RadCon monitor was used in close proximity).

Baseline System

The baseline technologies used were WBGT and heat stress training.

The WBGT is composed of a dry bulb, wet bulb, and globe thermometer, which are used to measure environmental conditions. The instruments were used to obtain environmental measurements; the readings were used to calculate the Heat Stress Index (American Conference of Governmental Industrial Hygienists).

In addition to the WBGT measurements, heat stress training is provided to workers to educate them on recognition and prevention of heat stress indicators. Training sessions typically last 1 hour.

The baseline technology relies on predicted responses of average populations to various environmental conditions and does not take into account individual worker health and physical condition. In addition, it relies on the workers' ability to recognize heat stress symptoms in themselves or coworkers, which is based on the individual comprehension of the symptoms. Use of personal protective clothing and respirators often inhibits the ability to visually detect heat stress symptoms.

■ Technology Demonstration Results

Key Demonstration Results

This system was successfully demonstrated at the C Reactor with the following key results:

- Provided real-time physiological monitoring and logged the data automatically in the computer database for future use.
- Demonstrated ability to preset alarm levels for each of the four real-time monitoring channels.
- Demonstrated ability to establish data bases for individual employees with alarm set points specific to the employee, depending on the individual's physical condition and abilities.
- Accuracy in triggering alarm set points, preventing potential heat stress and ensuring protection of human health:
  - During the demonstration, high alarms were set off 14 times for heart rate.
  - During the demonstration, high alarms were set off more than 50 times for activity level.
  - Sustained elevated heart rates, more than 18 seconds, were detected during monitoring activity. (Heart rates were successfully lowered by modifying work activities.)
- Proven very well suited for monitoring temperature and other vital signs.
- Proven very useful from a safety and industrial hygiene viewpoint because of increased ability to protect workers.
- Provided supervisors the ability to observe the real-time physiological condition of their employees.
- Capability to provide information that can be used to adjust worker stay time, which could contribute to increased productivity.
- Transmission signal was able to pass through structural (walls and floors) barriers with holes or pipes running through the length of the barrier.
- Unable to receive system signal through torturous paths (e.g., from a tunnel below grade to outside of the C Reactor).
- When located in close proximity, the HSMS experienced minor interference with other instrumentation.

- Equipment costs $3,600 for the bast station and software, plus $3,500 per sensing/transmitting set, with rental options available at 10% of purchase price per month.
- Spread spectrum technology provides capability for wireless signal transmission over 300 m (1,000 ft).

Successes

The HSMS proved to be an effective tool for monitoring the physiological conditions (temperature and other vital signs) of employees in real-time as they work. The system was accurate in triggering alarm set points, which can help prevent heat stress and ensure protection of human health by adjusting worker stay time. These abilities may also facilitate an increase in worker productivity. The spread spectrum technology provides capability for wireless signal transmission of over 300 m (1,000 ft), making it easy for workers to move about and perform unencumbered work activities.

Shortfalls

The HSMS was unable to receive system signals through torturous paths (e.g., from a tunnel below grade to outside of the C Reactor). This was solved, however, by setting up the receiving station closure or moving the receiver antenna closure to the subject. In addition, when located in close proximity, the HSMS experienced minor interference with one of the radiological instruments (Eberline 600) used at the site.

■ Comparison of Innovative Technology to Baseline

Table 3 summarizes performance and operation of the innovative technology compared to the baseline technology.

Table 3. Comparison of innovative and baseline technologies

Activity or Feature	**Innovative**	**Baseline**
	HSMS	WBGT
Setup[a], minutes	20	15
Flexibility	No electric cord, good	Same
Safety[b]	Very good, better than baseline	Good
Durability	Note c	Note c
Ease of operation	Easy, requires basic computer knowledge	Easy
Waste generation	None	None
Utility requirements	Battery	None
Training	Same	Same

NOTES:
a. Average times.
b. The innovative technology provides physiological data and computerized capabilities for accumulating and updating data on individuals and for alarming that are not possible with the baseline.
c. The WBGT is susceptible to damage and needs calibrations. The innovative system has more components and a computer, which are susceptible to damage, but no post-factory calibrations are needed unless the design is changed.

Because of the variety of functions and facilities, the DOE complex presents a wide range of D&D work conditions. The working conditions for an individual job directly affect the manner in which D&D work is performed for an individual job. The innovative and baseline technology evaluations presented in this report are based upon a specific set of conditions or work practices present at the Hanford Site, and are listed in Table 4. This table is intended to help the technology user identify work item differences between baseline and innovative technologies.

Table 4. Summary of variable conditions

Variable	HSMS Technology	Baseline Technology
Scope of Work		
Location of test area	C Reactor Building area	C Reactor Building area
Nature of work	Variety of D&D activities	Variety of D&D activities
Work Environment		
Level of contamination in the test areas	Contaminated (fixed and loose) and clean areas	Contaminated (fixed and loose) and clean areas
Work Performance		
Technology acquisition means	Recording vital body parameters (temperature and heart beat) on-line (real time)	Recording environment temperature and observation of workers
Compliance requirements	Compliance is assumed to be that necessary to meet requirements for typical heat stress monitoring	Compliance is assumed to be that necessary to meet requirements for typical heat stress monitoring

Meeting Performance Objectives

The objectives listed earlier in this section were all met by the MiniMitter HSMS.

Skills/Training

Required training for D&D workers using the HSMS was minimal (approximately 5 minutes of instructions). Workers needed to learn how to use the probes and how to properly install them on themselves. Setting up and operating the system properly required approximately 1 hour of instruction. The instruction was provided to the C Reactor personnel by the vendor's representative.

Operational Concerns

The HSMS is a computer-driven heat stress monitoring system that requires the operator to be familiar with the basics of an IBM-based PC. Although the transmitter and receiver units have been modified for rugged conditions, the units must be handled with care. In addition, the operator and user should take all usual safety precautions prior to operating the system. Also, if this system is used in radiologically contaminated areas, proper radiological work practices and engineering controls should be taken to prevent personnel or any system components from becoming contaminated.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

- This technology can be used at DOE and other public and commercial sites where workers may be exposed to the dangers of heat exhaustion or heat stress.
- This technology is effective at radiologically contaminated sites where personnel are required to wear protective clothing and/or perform tasks in higher temperature areas.
- The HSMS can be used both inside and outdoors.
- This technology is well suited for on-line heat stress monitoring (increases the chance of detecting a heat stress situation).

Competing Technologies

- This technology competes with other monitoring systems, such as a data logger, which record and store body temperature and heat rate. The competing technologies do not report data in real-time, rather are accessed after the personnel exit the job area. Therefore, competing technologies are not as effective at providing information for proactive decision-making regarding health and safety management.
- An alternative method to the MiniMitter HSMS is the baseline technology, the conventional WBGT and heat stress training provided to employees.

Patents/Commercialization/Sponsors

This technology is patented and commercially available though MiniMitter.

SECTION 5

COST

■ Introduction/Methodology

This cost analysis of the MiniMitter VitalSense Telemetry HSMS describes the cost of the equipment and provides a rough assessment of cost avoidance potential through implementation of this technology. In general, the HSMS has a capital cost of $3,500 per sensor unit (not including cost for base station), and may help avoid the occurrence of heat stroke, which can cost as much as $16,700 per occurrence. A rigorous cost comparison with the baseline technology was not performed because the cost avoidance related with an incidence of heat stroke would be infrequent (due to the conservative work control procedures employed at DOE sites). Also, no other cost savings are assessed here, such as improved worker productivity, that might result from implementation of the HSMS. For commercial applications, however, the vendor advertises improved worker productivity because situations are avoided where conservative safety procedures require the workers to needlessly exit the work area. These savings are not likely to be realized for DOE work in which conservative worker safety procedures may continue to govern work, despite use of the HSMS.

■ Cost Analysis

The innovative technology is available from the vendor in the forms and at the rates indicated in Table 5:

Table 5. Innovative technology acquisition costs

ACQUISITION OPTION	ITEM	COST
Equipment purchase (does not include required portable computer)	Base station & Software Sensor Unit Replacement Batteries	$3,600 $3,500 $95.00
Purchase	Temperature probes, in lots of 10 or more	$12.50/each
Purchase	Activity sensor	$85/each
Rental	per month (3 month minimum)	10% of purchase price

The rates and prices shown do not include shipping costs, but do include the heart rate option. Additional expense should be expected for an industrial hygienist to establish work procedures that consider the use of the HSMS (approximately 3 days of effort) and for training field safety personnel in using the HSMS with the new work procedures. The time required to don and doff work clothing is slightly increased (3 minutes to 5 minutes) for attachment of the sensor unit. The battery is anticipated to have a service life of 1 year. Maintenance costs will vary depending upon the nature of the work and severity of handling by the workers, but may be as much as $1,000 per year (for radio transmitter replacement), averaging $50 to $200 per year.

■ Cost Conclusions

The use of the equipment does not require adding special safety personnel. Attaching the sensor to the workers and developing monitoring summary histories is not a significant additional effort. The significant costs for this technology are one-time capital costs and costs for developing safety work procedures and training.

This technology is believed be more reliable for avoiding incidents of heat stroke than current safety procedures. The national average industry cost for a lost time accident is $16,700 and includes costs for emergency transport, treatment, incident reporting, and processing accident claims. The reference to a specific value of cost for heat stroke does not imply a specific cost savings for the HSMS. Rather, the presentation of this cost information is intended as a frame of reference for the larger issues of worker safety.

The recent 5-year average for heat stress lost-time at the Hanford Site is 7.6 cases per year; for the DOE Complex it is 43.8 cases nationwide per year, based on the number of cases shown in Figure 5 and as reported in CompWatch (http://www.he.net/~bsiweb/rateform.htm) and the Computerized Accident/Incident Reporting System (CAIRS) data base. The corresponding average total cost is $127,000/yr for the Hanford Site and $731,000/yr for the DOE Complex. The average workforce at the Hanford Site for the recent 5 years is 17,347, of which approximately one-third are routinely exposed to industrial hazards. Of this one-third, approximately 10% are dressed in double PPE or wearing respirators during work time, amounting to 578 workers. If half of these workers (289) are deemed to be working in potential heat stress conditions and are monitored with the improved technology, then 29 monitoring systems would be needed for the Hanford Site, since each system monitors 10 workers. If heat stress incidents are eliminated from the 289 workers, it could potentially avoid virtually all of the 7.6 lost-time cases per year.

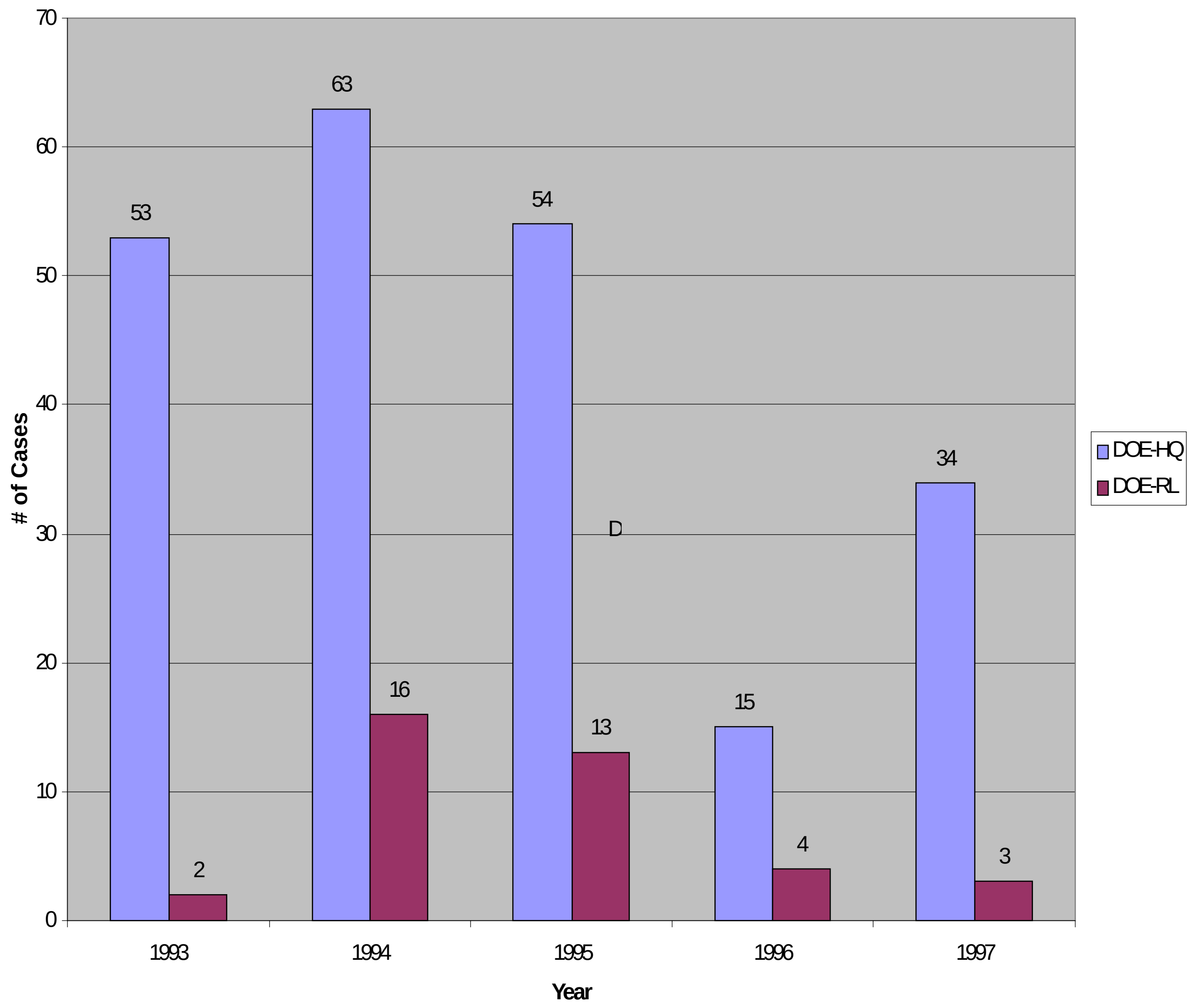

Figure 5. Yearly heat stress cases.

At $16,700 (DOE Occupational Injury/Illness and Property Damage Summary Report - EH-51) cost avoidance per potential occurrence, the average savings for each 10-worker system is calculated as follows:

($16,700/case) x (10/289) x (7.6 cases/yr) = $4,390/yr average

The corresponding yearly costs are calculated as shown below, based on Figure 5 above.

Investment costs per system: $3600 + $3500 + $850 for 10 activity sensors =	$7,950
Add 10 % freight and tax and 24% procurement costs	$2,700
Total investment per system	$10,650
Yearly amortization costs for 5-year life	$2,130/yr
Yearly operating and maintenance costs, assuming temperature probes are replaced 10 times/yr and batteries once/yr, and maintenance costs are midway between the average given at the end of the Cost Data section above: $1250 (temperature probes) + $950 (batteries) + $125 (maintenance) =	$2,325/yr
Total yearly costs for one system handling 10 workers	$4,455/yr

These costs closely match the potential average cost avoidance. The conclusion is that although use of the improved technology might be justified purely on the basis of improved safety, it has the potential to pay for itself.

Using the same reasoning, if workers were monitored in the entire DOE Complex with the improved systems, the technology has the potential to pay for itself nationwide.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

- The HSMS is a heat stress monitoring device used for monitoring of the vital body signs, such as body temperature and heart rate, and there are no special regulatory permits required for its operation and use.
- The wireless transmission system does not require FCC licensing.
- This system can be used in daily operations within the requirements of 10 CFR, Parts 20 and 835, and proposed Part 834 for radiological protection of workers and the environment, and OSHA guidelines (29 CFR).
- Although the demonstration took place at a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site, no CERCLA requirements apply to the technology demonstrated.

Safety, Risk, Benefits, and Community Reaction

Worker Safety

- Normal radiation protection worker safety instructions used at the facility would apply when used in radiologically controlled areas.
- Technology users should implement contamination control practices when used in contaminated or potentially contaminated areas.
- Normal electrical grounding requirements should be met for recharging the batteries using the system battery charger; 115 VAC power outlets should be used.
- Normal worker safety precautions and practices prescribed by OSHA for operation of equipment should be followed.

Community Safety

- It is not anticipated that implementation of the HSMS would present any adverse impacts to community safety.
- No socioeconomic impacts are anticipated.

Environmental Impact

- There is no adverse impact on the environment.

SECTION 7

LESSONS LEARNED

■ Implementation Considerations

- There are no specific implementation considerations except work force attitude toward acceptance of new systems.

- The HSMS technology can be used for interior and exterior areas.

- The HSMS technology can be used in the contaminated areas.

- HSMS does not produce secondary waste.

- The HSMS is very well suited for monitoring workers in areas with high ambient temperatures and/or when personal protective clothing or respirators must be worn. The health and safety benefits make the technology attractive.

■ Technology Limitations/Needs for Future Development

- The transmission signal has some limitations, and the base station location should be tested when being used in areas with thick concrete or steel obstructions. (The range can be readily improved by using either a taller antenna or moving the antenna closer to the monitors with a coaxial cable connection to the base station.)

- Except for the carrying pouch, the demonstration at the C Reactor indicated no need to modify features of the HSMS.

■ Technology Selection Considerations

- The technology is suitable for DOE nuclear facility D&D sites or any other sites involving D&D or remediation activities in contaminated areas, in areas where personal protective clothing is required, or where high ambient temperatures exist.

- The technology monitors individual human vital signs and does not rely on an individual's predicted reaction to various environmental conditions.

- The technology eliminates the need for 115 VAC electric power outlets during the monitoring.

- The technology inherently reduces the potential for heat stress situations (on-line/real-time monitoring adds to safety when used high-temperature tasks or highly contaminated areas requiring multiple personal protective equipment).

APPENDIX A

REFERENCES

10 CFR 20, "Standards for Protection Against Radiation," *Code of Federal Regulations*, as amended.

10 CFR 834 (Proposed), "Environmental Radiation Protection," *Code of Federal Regulations*, as amended.

10 CFR 835, "Occupational Radiation Protection," *Code of Federal Regulations*, as amended.

29 CFR 1910, "Occupational Safety and Health Standards," *Code of Federal Regulations,* as amended.

29 CFR 1926, "Regulations for Construction," *Code of Federal Regulations,* as amended.

Reneau, P. D., and P. A. Bishop, 1996, *Validation of a Personal Heat Stress Monitor*, J. AIHA, 57:650, July 1966.

Weiss, M. E., A. F. Pue, and J. Smith, 1991, "Laboratory and Hospital Testing of New Infrared Tympanic Thermometers," *J. Clinical Engineering*, 2:137, March 1991.

APPENDIX B

ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Description
BHI	Bechtel Hanford, Inc.
bpm	beats per minute
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
FCC	Federal Communications Commission
FETC	Federal Energy Technology Center
HSMS	heat stress monitoring system
ISS	Interim Safe Storage
LSTD	Large-Scale Technology Demonstration (Project)
OSHA	Occupational Safety and Health Administration
PC	personal computer
RL	U.S. Department of Energy, Richland Operations Office
USACE	U. S. Army Corps of Engineers
VAC	Volts, alternating current
WBGT	wet bulb globe thermometer