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PIT-STORAGE MONITORING

by

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ABSTRACT

Plutonium pits retrieved during the dismantlement of nuclear weapons are presently being stored in earth-covered magazines in Zone 4 at the Pantex plant in Amarillo, Texas. Delays in the development and certification of an approved long-term storage facility indicate that these pits are likely to remain at Pantex for the foreseeable future. Because these magazines are not protected by any environmental control systems and because the number of pits per magazine is high, temperatures within the magazines can, and sometimes do, rise to temperatures higher than optimum for pit storage. Scientists from Los Alamos and Lawrence Livermore national laboratories, as well as from the Pantex plant, operated by Mason & Hanger, have collaborated to design a joint modeling/experimental program that will enable scientists to understand heat-flow phenomena in pit-storage magazines. Our efforts have focused on developing the capability to predict temperatures of stored pits. We are using environmental information gathered primarily from the Pantex pit-storage facility to develop empirical predictive tools as well as three-dimensional heat-flow models.

I. INTRODUCTION

Since the end of the Cold War and the disintegration of the Soviet Union, the United States has pursued a rigorous nuclear-weapon dismantlement program at the Pantex plant in Amarillo, Texas. Nuclear systems not included in the retained stockpile are gradually removed from their "on alert" status and, subsequently, as staging room becomes available, transported to Pantex for dismantlement. Reductions in nuclear warhead storage capacity at military bases slated for closure and delays in the development of permanent long-term storage facilities for high-level nuclear waste have resulted in some urgency in carrying out this process. Thus, slowdowns in the pace of dismantlement at Pantex have far-reaching ramifications.

The Department of Energy (DOE) hopes to dismantle approximately 2,000 warheads a year at the Pantex plant. A total of 15,000 to 20,000 warheads not slated for retention in the enduring nuclear weapons stockpile will eventually be retired. Special nuclear material (SNM) in the pits recovered from these warheads as they are dismantled must be stored somewhere. Under its existing environmental assessment, Pantex has permission to store up to 12,000 pits. The guidelines of an environmental impact study presently under way may result in a DOE decision to allow Pantex to store 20,000 pits. Pit storage, wherever it occurs, is not likely to be a short-term operation not only for the reasons already cited but also because the closure of the Rocky Flats Plant near Denver precludes the recycling needed if such pits are to be reused. Indeed, DOE has neither permanent long-term storage facilities nor recycling facilities for managing plutonium pits from dismantled nuclear weapons.

Pits from dismantlement are presently stored in Pantex's Zone 4 storage and staging area, which encompasses 18 modified Richmond magazines, with two sides per magazine (Fig. 1), and 10 steel arch construction (SAC) magazines (Fig. 2) dedicated to pit storage. The remaining magazines in Zone 4 are used for staging weapons that supply the dismantlement-process line.

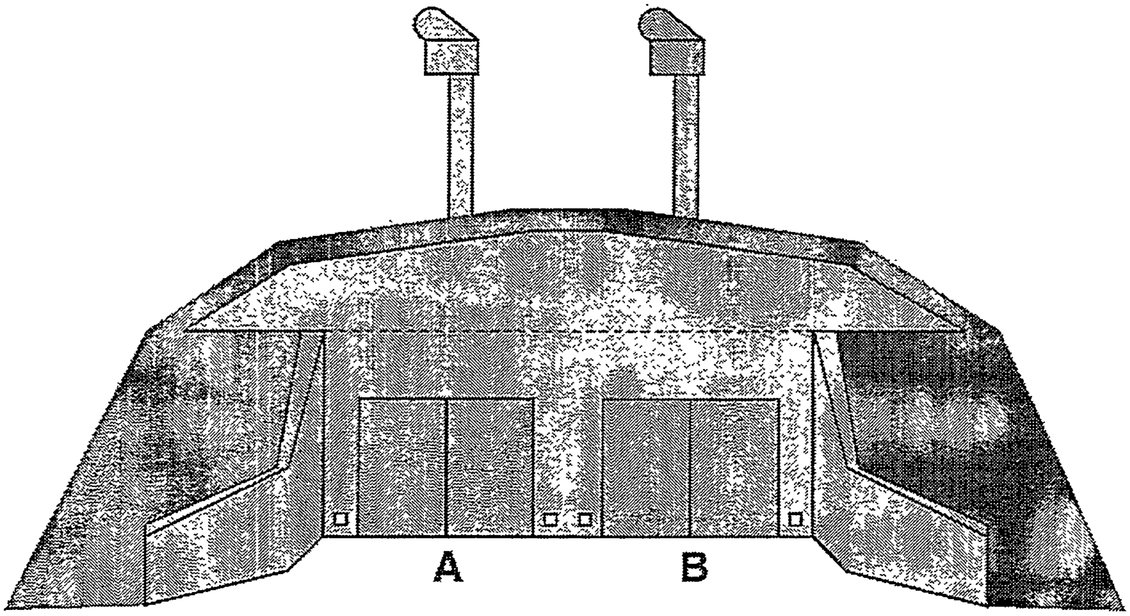

Fig. 1. Artist's rendering of modified Richmond magazine.

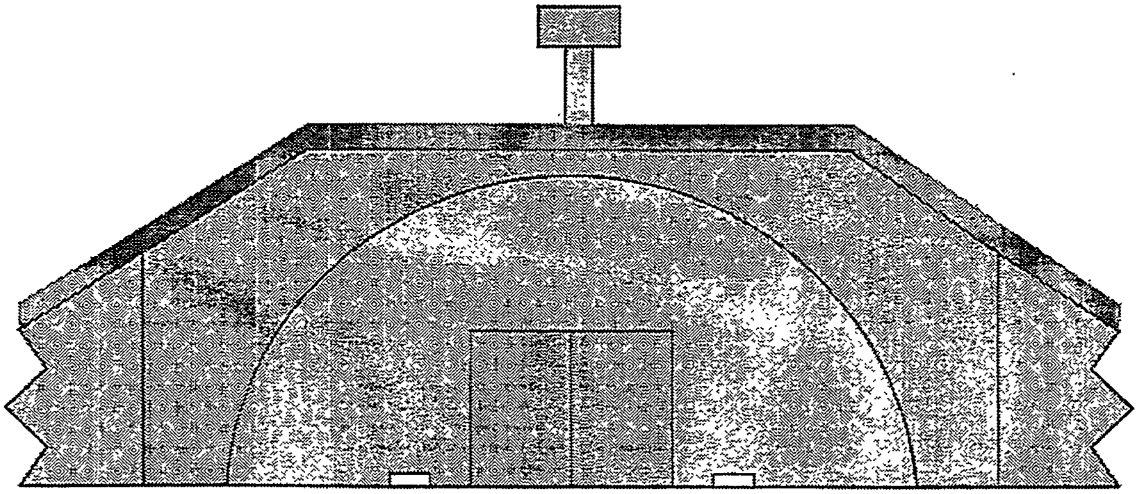

Fig. 2. Artist's rendering of SAC magazine.

The total of 28 magazines represents relatively limited space for storing the roughly 20,000 pits expected from warhead dismantlement. Consequently, a high pit-packing density (that is, storing a large number of pits in each magazine) is required to accommodate the expected inventory. The definition of "high pit-packing density" has evolved as the need for increased pit-storage capacity has become more evident. Originally, a total of 120 pits were stored in 5 columns of 24 rows in each modified Richmond magazine. This loading configuration was dubbed the "original." The next evolution in pit-loading configuration allowed for storage of an additional 48 pits by adding 2 additional columns of 24 pits in AL-R8 cans* on casters. This configuration was dubbed "dense pack" (Fig. 3). The most recent pit-loading configuration is 106 pits held horizontally along each wall of a modified Richmond magazine, for a total of 212 pits in the so-called stage-right loading configuration (Fig. 4).

Because of natural radioactive decay, each plutonium pit is an intrinsic heat source, producing as much as roughly 18 watts in heat load. The total heat load in any storage magazine is a function of the number and type of pits stored in it. Currently, magazine heat loads at Pantex can reach as high as a few kilowatts—an amount sufficient to raise internal magazine temperatures well above ambient. Elevated magazine temperatures are a cause of concern because of corresponding elevations in pit temperatures. Because the AL-R8 containers are primarily designed to keep heat from external sources from entering the pit and to protect the pit in the event of a fire, their design also serves to prevent heat produced by the pit from escaping. Thus, depending on pit wattage, relatively high differences in temperature (ΔTs) from pit to can can occur. Some high-wattage pits, with ΔTs greater than 50°C, are known to have reached temperatures near 150°C while stored in Zone 4.

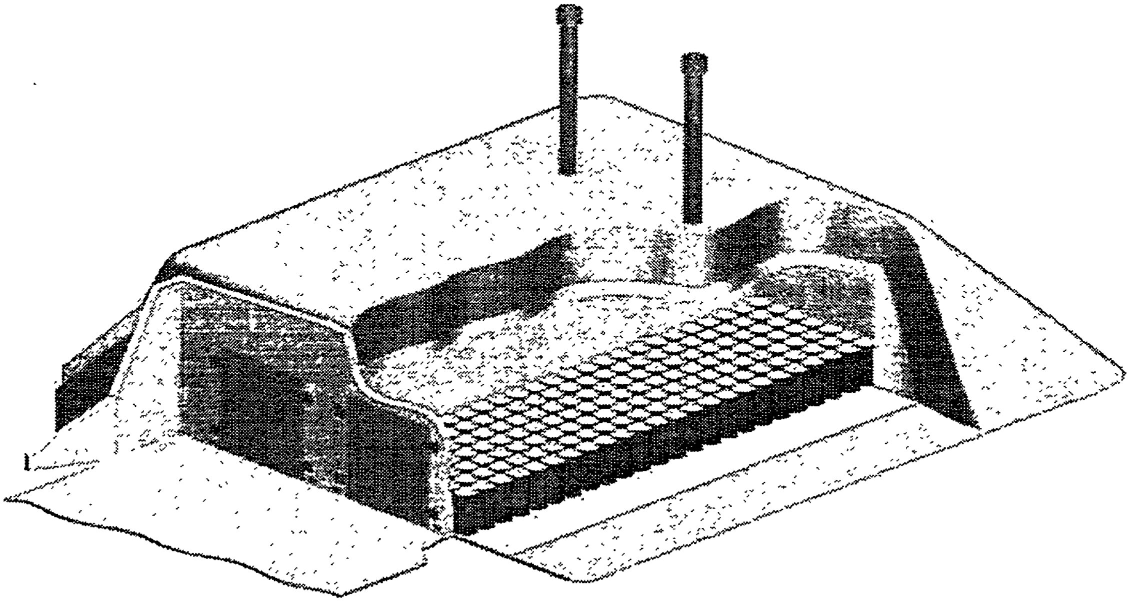

Fig. 3. Artist's rendering of dense-pack loading configuration.

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*AL-R8 storage containers resemble 35-gallon steel drums filled with a fire-resistant insert called Celotex.

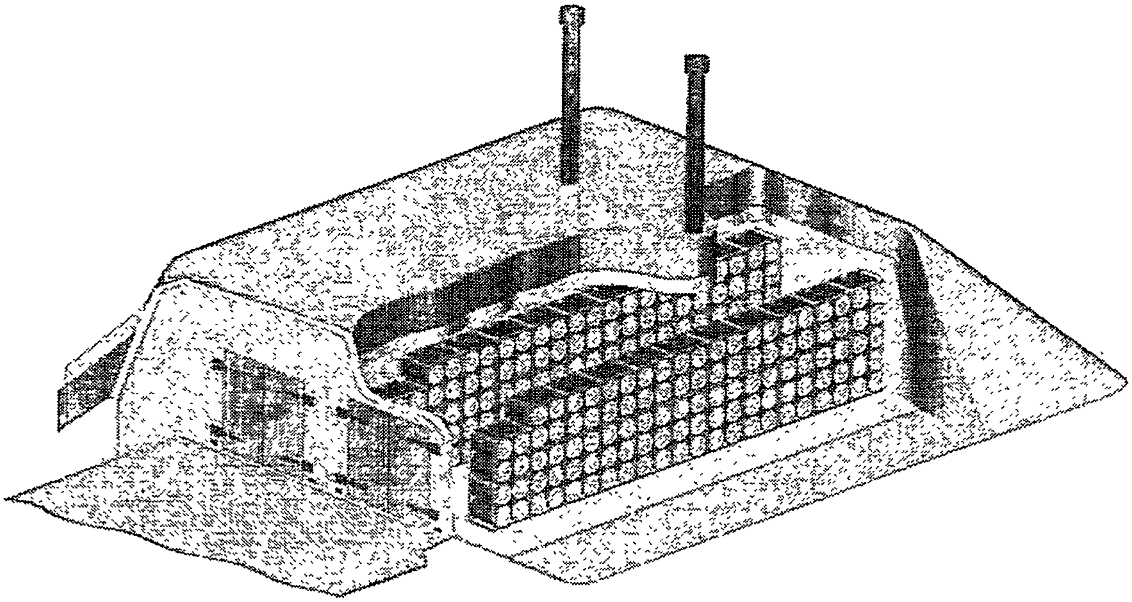

Fig. 4. Artist's rendering of stage-right loading configuration.

Elevated pit temperatures are a cause for concern among DOE scientists for a number of reasons. First, for a small number of pits, there is a safety concern. The weld holding certain types of pits together can fail if the temperatures reached are high enough. Weld failure could result in localized contamination from plutonium oxide. Second, the aging characteristics of pits vary with temperature. An elevated storage temperature will certainly accelerate the aging process and could alter the familiar mechanisms by which pits are known to age. That is, pits stored at excessively high temperatures will rapidly age beyond the realm of experience and knowledge of the DOE scientists responsible for their safe storage. Third, the United States has invested a tremendous amount of money and effort in manufacturing pits for nuclear weapons. To obtain the maximum benefit from this investment, we must ensure that those pits that are good candidates for potential reuse are stored in an environment that retards or prevents undesirable aging effects.

II. PIT-STORAGE MONITORING PROGRAM

To ensure the safety and viability of stored pits, DOE scientists need to understand pit-storage conditions. To further our knowledge in this area, scientists from Los Alamos and Livermore national laboratories and the Pantex plant initiated a combined experimental/modeling program in July 1993. Because of the urgency of this program and severe budgetary constraints, most experiments were performed on war reserve pits stored in Zone 4 at the Pantex plant. The experiments, by necessity, responded to immediate storage concerns with the potential for disrupting dismantlement. An atmosphere of urgency and the need to respond to immediate crises increase the difficulty of conducting any type of scientific investigation. The experimental environment was further complicated by the severe operational constraints imposed by Zone 4 and Zone 12 operating procedures for handling war reserve pits. In some instances, extremely useful, and seemingly simple, experiments could not be performed because of the operational constraints and formality of operations required when handling war reserve items.

To facilitate the necessary pit monitoring activities, we developed an overall stewardship program that followed three main steps:

- Gather environmental data such as temperatures of pits, AL-R8 cans, magazine air, surfaces, and berms, as well as magazine-air humidity.
- Develop models for predicting pit temperatures as a function of magazine and outdoor ambient temperatures.
- Develop models for predicting magazine temperatures as a function of ambient outdoor temperatures.

A. Data Gathering

To build the desired predictive models, we needed detailed records of pit, magazine, and ambient temperatures. Los Alamos scientists had extensive experience with Campbell Scientific dataloggers, which they had used in the Stockpile Monitor Program.* The Campbell Scientific CR10 is a rugged, well-tested datalogger/controller that can collect up to 12 single-ended channels of environmental information and store data in 64 kilobytes of permanent memory. Simple algorithms that sort the data into meaningful sets, such as average, maximum, and minimum values, are easily programmed into the CR10. Dataloggers are housed in sturdy, weather-proof, fiberglass enclosures that can be located outside. As a hedge against data loss because of inadvertent power loss to the CR10, an auxiliary external storage module (the SM192) with battery-backed RAM (random access memory) is attached to each datalogger.

Measurements of air, surface, and soil temperatures support the modeling effort. We used YSI 010-44019A thermistors to obtain air and soil temperatures and YSI 082-44019A thermistors to obtain surface temperatures of the pit, wall, and floor. These thermistors function between -55°C and +85°C and are accurate to within ±1.5°C within the range of temperatures experienced during our experiments. To take surface-temperature measurements, we attached the thermistors by placing the active thermistor surface against the surface of interest and then potting over the back of the thermistor with Cabosil-loaded Sylgard 186. A 0.125-in.-thick Styrofoam pad was placed over the potting and taped in place. The function of the Cabosil/Sylgard and Styrofoam was to ensure the recording of accurate surface temperatures rather than some mix of surface and surrounding air temperatures.

Data-gathering efforts in Zones 4 and 12 have evolved from a relatively simple first effort in August 1993 to a complex, constantly evolving effort today. Details of all the data-gathering experiments are beyond the scope of this report. Rather, we will present a historical listing of major efforts and provide details regarding one representative instrumentation activity.

- August 1993: 24 channels of data from a modified Richmond magazine (number 34 in the B side), which included two W48 pits and AL-R8 containers.
- January 1994: 48 channels of data from a dense-packed modified Richmond magazine (also number 34 in the B side), which included 12 pits and containers.
- March 1994: 20 channels of data from pits and containers in Zone 12, a controlled-temperature environment with vertical/horizontal container orientation.
- March 1994: 12 channels of data from a dense-packed SAC magazine (number 107), which included 7 containers.

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*The Stockpile Monitor Program at Los Alamos is a continuing effort to characterize the environmental conditions of weapon storage areas around the world. See Los Alamos National Laboratory report LA-12796-MS, "The Stockpile Monitor Program," by G. Buntain, M. Fletcher, and R. Rabie (July 1994).

- August 1994: 48 channels of data from a stage-right packed modified Richmond magazine (number 21 in the A side), which included 16 pits and containers.
- August 1994: 23 channels of data from a stage-right packed modified Richmond magazine (number 21 in the B side), which included 16 containers.
- September 1994: wind-speed anemometer and solar panels added to two magazines in Zone 4.
- October 1994: 38 channels of data from a stage-right packed SAC magazine (106), which included 16 pits and containers.
- Numerous simple installations and reconfigurations of instrumentation.

1. Magazine 21A Instrumentation. The instrumentation at modified Richmond magazine 21A is representative of much of the work performed in Zone 4. Magazine 21A is the first magazine to be loaded in a stage-right configuration with 212 pits oriented horizontally for a total heat load of a few kilowatts. A total of 48 data channels are collected in 21A. Details of each data channel are listed in Table I.

Pit and can thermistor locations are identified according to the alphanumeric grid detailed in Fig. 5. The instrumented pits are shaded and the type of pit detailed. The "A" through "E" designators refer to pit-wattage ranges, with A-type pits being the least hot and E-type pits the hottest.

Air- and surface-temperature monitoring locations in 21A and 21B are detailed in Fig. 6. Additionally, relative humidity inside and outside 21A is monitored as well as soil temperatures at four depths in the berm.

We record temperatures every minute and average them every four hours. Maximum temperatures and the time they occurred within each four-hour interval are also recorded for each probe. Data are saved as comma-separated ASCII and are easily imported into any spreadsheet. A representative plot of magazine temperatures appears in Fig. 7. A representative plot of pit temperatures is presented in Fig. 8.

2. Modeling. Our goal was, and is, to develop the capability of predicting the relationship between pit and outdoor ambient air temperatures as a function of pit type, location, and orientation. This is an ambitious goal and one we could not realistically meet in the short term. Thus, the necessity of responding to immediate questions regarding pit temperatures in Zone 4 forced us to pursue both empirical and nonempirical methods. We used two empirical methods to predict pit temperatures and developed a lumped-parameter model to predict pit-to-can ΔTs. Our effort to develop a three-dimensional magazine heat-flow model is ongoing.

a. Empirical Models. One method of predicting the maximum temperature of any given pit is to simply sum pertinent measured temperatures. This method works fairly well as long as it is applied judiciously. It does not work if pit location, packing configuration, or wattage is significantly varied. The summing is performed as follows:

$$T_{\text{pit}} = T_{\text{ambient}} + \Delta T_{\text{magazine to ambient}} + \Delta T_{\text{AL-R8 to magazine}} + \Delta T_{\text{pit to AL-R8}} ,$$

where

T_{ambient} is obtained from weather records,

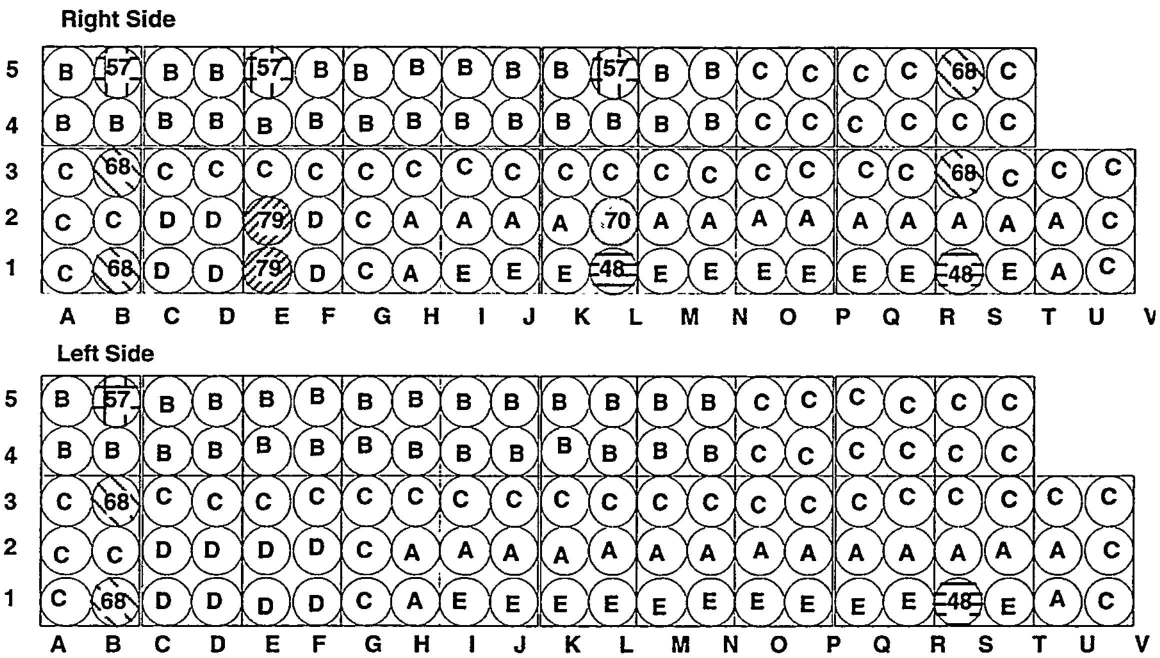
$\Delta T_{\text{magazine to ambient}}$ is measured in the magazine,

$\Delta T_{\text{AL-R8 to magazine}}$ is measured as a function of pit environment, and

$\Delta T_{\text{pit to AL-R8}}$ is measured as a function of pit wattage.

TABLE I. Modified Richmond Magazine 21A Probe Identification

Probe	Type	Location
1	Surface	RS1 48 Pit
2	Surface	RS1 48 Can
3	Surface	RS3 68 Pit
4	Surface	RS3 68 Can
5	Surface	RS5 68 Pit
6	Surface	RS5 68 Can
7	Surface	LS1 48 Pit
8	Surface	LS1 48 Can
9	Surface	RL1 48 Pit
10	Surface	RL1 48 Can
11	Surface	RL2 70 Pit
12	Surface	RL2 70 Can
13	Surface	RL5 57 Pit
14	Surface	RL5 57 Can
15	Surface	RE2 79 Pit
16	Surface	RE2 79 Can
17	Surface	RE1 79 Pit
18	Surface	RE1 79 Can
19	Surface	RE5 57 Pit
20	Surface	RE5 57 Can
21	Surface	RB1 68 Pit
22	Surface	RB1 68 Can
23	Surface	RB3 68 Pit
24	Surface	RB3 68 Can
25	Surface	RB5 57 Pit
26	Surface	RB5 57 Can
27	Surface	LB1 68 Pit
28	Surface	LB1 68 Can
29	Surface	LB3 68 Pit
30	Surface	LB3 68 Can
31	Surface	LB5 57 Pit
32	Surface	LB5 57 Can
33	Air	Air temperature centered 3 ft from back, 8 in. down
34	Air	Air temperature centered 22 ft from back, 8 in. down
T35	RH/Temp	Air temperature centered at door, 8 in. down
R35	RH/Temp	RH centered at door, 8 in. down
36	Surface	Surface temperature of partition wall, 22 ft back, 4.5 ft up
37	Surface	Surface temperature of outside wall, 22 ft back, 4.5 ft up
38	Surface	Surface temperature of floor, 22 ft back, centered
T39	RH/Temp	Outside air temperature
R39	RH/Temp	RH, outside
40	Soil	Top berm, 6 in. down
41	Soil	Top berm, 1 ft down
42	Soil	Top berm, 2 ft down
43	Soil	Top berm, 3 ft down
44	Air	At chimney opening
45	Air	Air temperature beside Probe 36 (22 ft back, 4.5 ft up, right side)
46	Air	Air temperature beside Probe 37 (22 ft back, 4.5 ft up, left side)



Right Side

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
5	B	57	B	B	57	B	B	B	B	B	B	57	B	B	C	C	C	C	68	C		
4	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C		
3	C	68	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	68	C	C	C
2	C	C	D	D	79	D	C	A	A	A	A	70	A	A	A	A	A	A	A	A	A	C
1	C	68	D	D	79	D	C	A	E	E	E	48	E	E	E	E	E	E	48	E	A	C

Left Side

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
5	B	57	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C		
4	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C		
3	C	68	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2	C	C	D	D	D	D	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C
1	C	68	D	D	D	D	C	A	E	E	E	E	E	E	E	E	E	E	48	E	A	C

Fig. 5. Pit layout in modified Richmond magazine 21A.

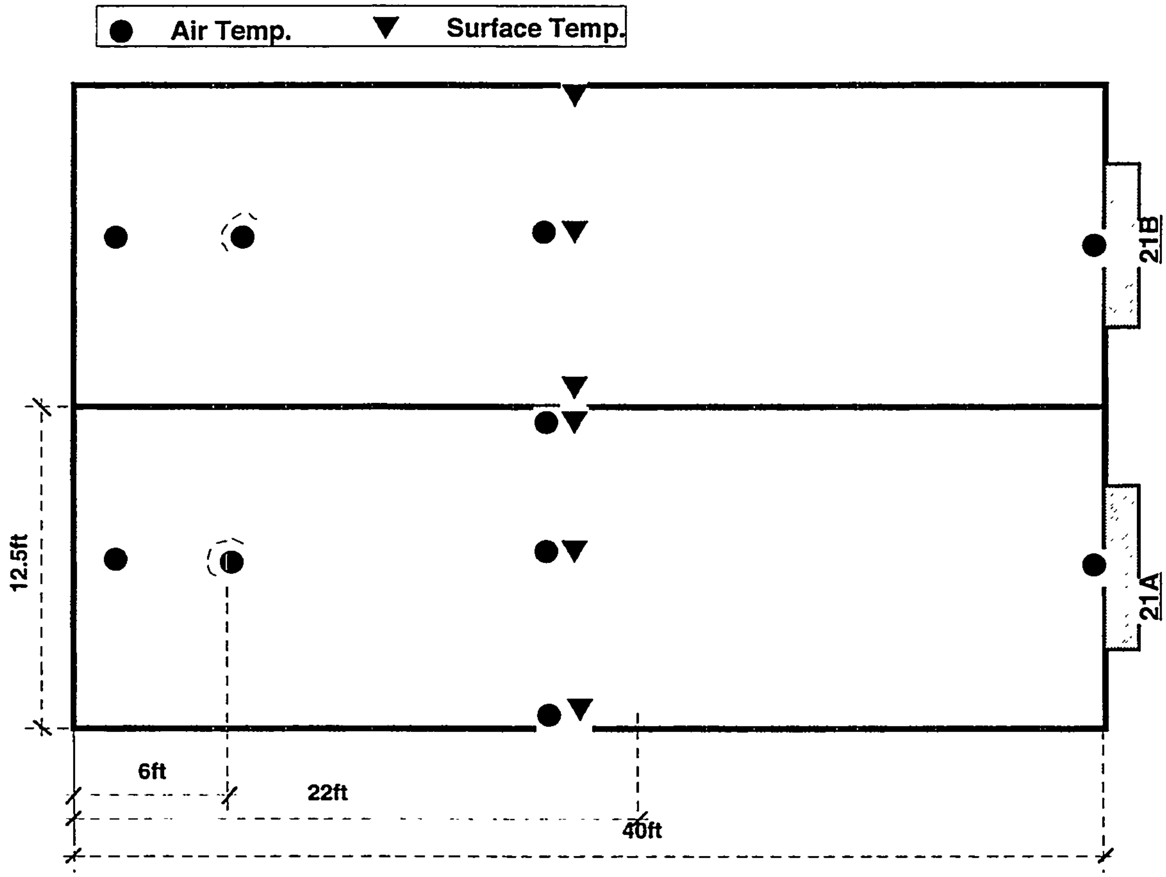


Fig. 6. Probe locations in modified Richmond magazine 21A and 21B.

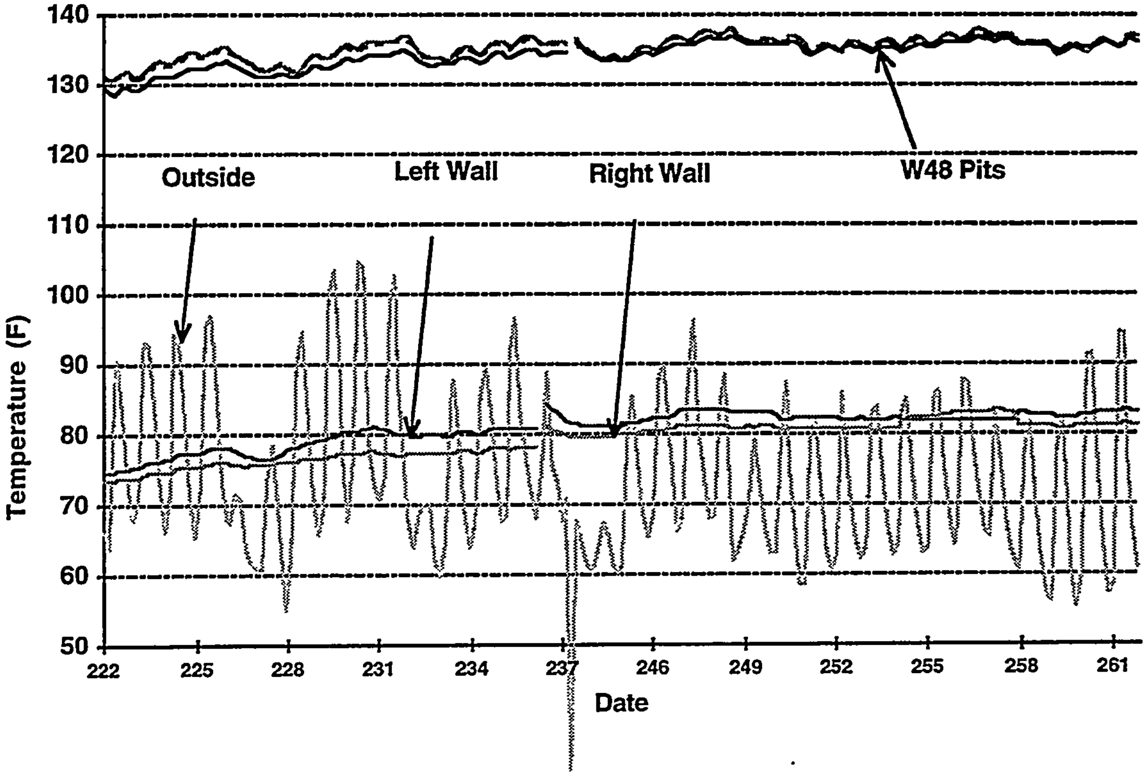


Fig. 7. Selected temperatures for modified Richmond magazine 21A (dates are Julian days between August 10 and September 18).

This method makes it possible to review historical weather data and predict that as long as $T_{ambient}$ or some function thereof (we typically used a 5-day running average) remains below some trigger point, T_{pit} will not rise above some acceptable value.

A second empirical method for predicting pit temperatures is to simply plot the temperature of any pit in question (we typically used the hottest pit or pits) versus either the 5-day running average outdoor ambient temperature or the 4-hour average magazine air temperature and to fit a simple polynomial. Polynomial fits are typically quite good, with an R^2 value of 0.96 or better (Fig. 9) and make it possible to predict pit temperatures for any given ambient or magazine air temperature. Plots with the 5-day running average are most useful for predicting margins of safety, but better fits are obtained using magazine temperatures. When this method is used, pits with dissimilar wattages, locations, or loading configurations must be considered separately.

b. AL-R8/Pit Lumped-Parameter Model. If one knows the $\Delta T_{pit\ to\ AL\text{-}R8}$ and the temperature of the air surrounding the can, one can predict pit temperature. Thus, we developed a lumped-parameter model using the TSAP (Transient System Analysis Program) code to predict $\Delta T_{pit\ to\ AL\text{-}R8}$. This model divides the AL-R8/pit into spatial "lumps," or regions, and takes into account heat flow through conduction, convection, and radiation across lump boundaries. The lumped-parameter model was benchmarked with data collected in Zone 12 using W48 pits and AL-R8 cans. Good agreement was obtained.

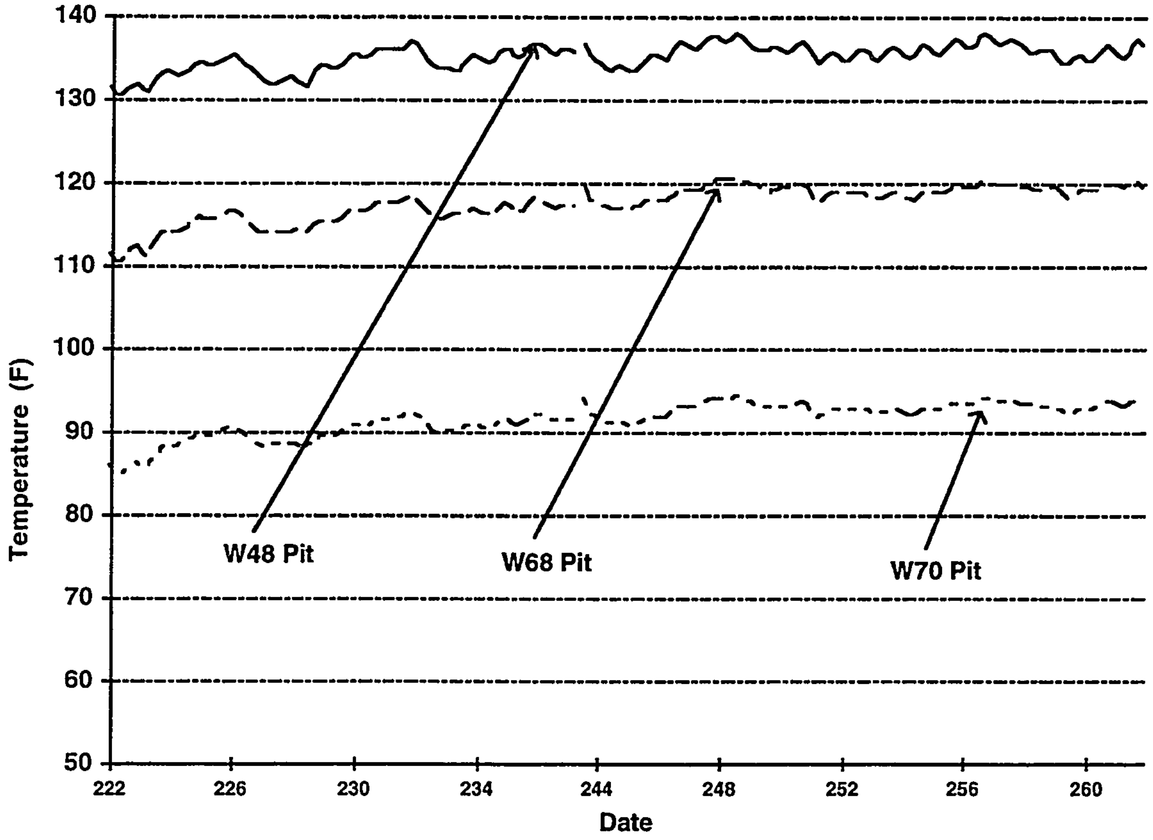


Fig. 8. Selected pit temperatures for modified Richmond magazine 21A (dates are Julian days between August 10 and September 18).

c. Three-Dimensional Fluid/Heat Transfer Model. Our ultimate goal is to predict the temperature of any pit given an outside air temperature. To accomplish this we need to know the $\Delta T_{\text{pit to AL-R8}}$ as well as the boundary air temperature at every AL-R8. We can predict the $\Delta T_{\text{pit to AL-R8}}$ using the lumped-parameter model just described. The missing piece of information is the boundary condition at the AL-R8. This boundary-air temperature is a function of magazine type, AL-R8 location, and loading configuration. Understanding the complex fluid flows and regional effects within magazines requires the use of a finite-volume, three-dimensional model. We have chosen to use "FLOW3D," a three-dimensional fluid dynamics code distributed by Computational Fluid Dynamics Services. This code takes into account natural convective air flow and temperature distributions within the magazine as well as convective heat transfer to the air and conduction to the magazine concrete walls and earthen berm. A time-varying outsidetemperature is also modeled. We benchmarked the model against temperatures measured in a dense-packed loading configuration and obtained good agreement for steady-state conditions. A diurnal temperature fluctuation is now being incorporated into the model.

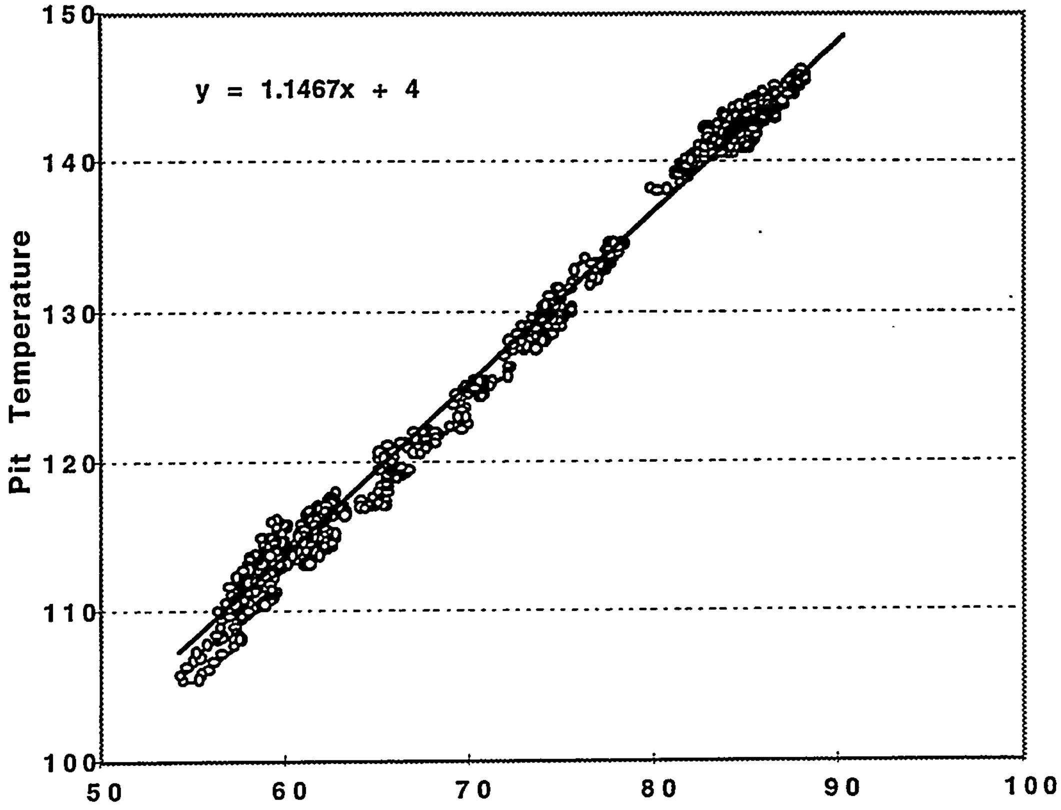


Fig. 9. Plot of temperature of hottest pit in modified Richmond magazine 34B vs ceiling temperature.

III. FUTURE ACTIVITIES

The future level of effort to improve the monitoring of the pit storage environment will largely be determined by funding availability. Our efforts will focus mainly on the following activities.

- We plan to refine modified Richmond magazine models (such as the three-dimensional finite volume model) and include a diurnal temperature fluctuation capability (initially, ±15°C).
- We plan to develop SAC magazine models for dense-packed and stage-right loading configurations.
- We plan to install hardware permitting remote data retrieval from dataloggers in Zone 4. This will be accomplished using a radio-frequency link to a dedicated RF/phone modem.
- We plan to install hot-wire anemometers in the chimneys of two well-instrumented magazines in Zone 4 to measure air flow for convective heat balance.
- We plan to install solar panels at each datalogger site to avoid the onerous task of battery replacement and provide a more reliable power supply.

- We plan to recommend a standard instrumentation scheme and data retrieval/handling procedure for every pit-storage magazine in Zone 4.
- We hope to test "passive" cooling methods that might be applicable for Zone 4 magazines. For example, we would like to try the following ideas :
  - Using heat pipes to transfer interior magazine heat to outside ambient air.
  - Optimizing chimney height/diameter to increase air flow through magazines.
  - Installing bimetallic doors in magazine vents to permit air flow when outside temperatures are cooler than those inside the magazine and to restrict air flow when they are hotter.
  - Covering magazine berms with white gravel and perhaps watering the soil to promote evaporative cooling.

Our efforts at evaluating passive-cooling methods are somewhat thwarted by the lack of a suitable facility. All the magazines in Zone 4 are consigned to keeping dismantlement on schedule and are, therefore, full and unavailable. Thus far, no suitable surrogate magazines have been located. We may test some of the aforementioned cooling methods on scaled models in environmental chambers located at Los Alamos if funding is available.