significantly reduced the protective barriers against fire hazards.

2.2.5 Management Systems

Contractual Background

The converter removal work in K-33 was conducted as part of a "work for others" project under various memoranda of understanding between the contractor for United States Enrichment Corporation (USEC), Lockheed Martin Utility Systems (LMUS), and LMES. Under a lease agreement between DOE and USEC, process equipment needed at Portsmouth and Paducah is available from K-25 facilities. Under this arrangement, LMUS identifies needed components and equipment (such as the converters in K-33) and negotiates costs and schedules with LMES, who then performs the equipment removal and subsequent shipment to LMUS. From OR's perspective, funding is made available to LMES and LMUS via a "Program 40" financial code. The K-33 equipment removal work under "Program 40" was funded by USEC and administered via the OR Office of Planning and Budget.

The work at K-33 was part of a "work for others" project.

LMUS requested six "000" converters; this equipment was available from K-33, Cell 7. Various memoranda between OR Office of Enrichment Facilities, LMES, and LMUS in 1996 and 1997 discuss the general task, and work was executed by LMES and LMUS consistent with contract provisions. However, OR basically delegated project arrangements to LMES and LMUS to negotiate. LMUS provided funding authorization; however, no firm schedules were identified, and project details were generally handled informally by telephone. There is evidence that the OR Office of Enrichment Facilities was aware of the work.

Under contract with OR, LMES maintains the K-25 Site and is bound to implement (among other contractual provisions) safety and health requirements, as specified in the contract (Section H-16) and the referenced Standards/Requirements Identification Documents. These requirements are, in turn, translated by LMES into operating procedures for completing work activities.

Oak Ridge Operations Office Roles and Responsibilities

OR organizational functions are described in generalized *Mission and Functions Statements.* However, lines of authorities and specific roles and responsibilities for activities categorized as "work for others" are not addressed. No evidence of other formal protocols or written instructions for DOE management and control

of "work for others" activities was identified. There was no evidence that OR has assumed line management responsibility for the K-33 converter removal work.

Portsmouth and Paducah programmatic responsibilities in OR are assigned to the Office of the Assistant Manager for Enrichment Facilities. Although aware of the equipment removal activities, the OR Office of Enrichment Facilities was not aware of the project planning or the identification of safety requirements, nor were they involved in safety and health monitoring of the converter work in K-33. During interviews, Enrichment Facilities management stated that such activities were not assigned to them and that they had not assumed any project responsibilities. Therefore, this Office did not communicate that equipment removal activities were being undertaken to the OR office with landlord responsibilities.

Roles and responsibilities for "work for others" are not defined.

For more traditional projects where OR provides direct funding, responsibilities and authorities established for OR elements involved in safety management are more clearly described. However, in this K-33 converter removal "work for others" activity, OR organizations below the first management level did not have clear expectations and understandings as to their safety responsibilities and authorities for planning, monitoring, and oversight. As a result of OR's recent transition to a matrix project organization, safety and health oversight is not emphasized by the OR Office of Environment, Safety and Health, which provides routine technical and oversight support to line organizations as requested.

OR Office of Enrichment Facilities management assumed that the OR Office of the Assistant Manager for Environmental Management and the K-25 Site Office would provide safety management and oversight of "work for others" being performed in K-33. However, this was not the case, since the K-25 Site Office was not actively engaged in monitoring or tracking the K-33 converter removal work, as discussed below.

Safety responsibilities and authorities for the K-33 "work for others" were not well understood below the Operations Office Manager level.

Office of the Assistant Manager for Environmental Management Roles and Responsibilities

During Board interviews, the OR Site Manager and the Assistant Manager for Environmental Management indicated that K-33 and the converter removal work responsibility would fall under the purview of the K-25 Site Office. During his interview, the K-25 Site Office Manager stated that this responsibility resided with the Environmental Restoration Division and was not within the purview

of the K-25 Site Office's landlord program. Further, the Assistant Manager for Environmental Management reinforced his understanding of responsibilities for K-33 by discouraging any Board followup with the Environmental Restoration Division Manager, because he was confident that the Environmental Restoration Division was not involved with the work.

There was no clear understanding of what OR organization was responsible for the work at K-33.

The Board determined that landlord responsibilities for K-25 (non-environmental restoration, sitewide facilities, support organizations) were assigned to the OR Office of the Assistant Manager for Environmental Management and to the K-25 Office. This Office, while responsible for surveillance and maintenance of the K-33 Building and activities undertaken therein, did not manage or monitor the converter removal work; therefore, they could not assure that appropriate requirements specified in the DOE authorization basis or other facility parameters (such as fire protection, OSHA compliance, electrical safety, and criticality safety) were adequately identified during planning and properly controlled during the work. In the absence of this involvement, the integrity of building safety systems and appropriate administrative controls while the building was in the "surveillance and maintenance" mode could not be assured.

OR K-25 Site Office personnel, while generally aware of the work activities, were not involved with the planning, did not inspect the work area, and did not provide oversight/monitoring of the converter removal work in Cell 7. No Environmental Restoration Division facility representative oversight was performed for this work, nor was there evidence that any oversight activities had been performed within K-33 for several months prior to the accident. Reviews of audit/assessment plans and reports for 1996 revealed that K-25 was evaluated from a sitewide systems and/or functional standpoint (e.g., fire protection, waste management, lockout/tagout, safety permit processes). However, there also was no evidence of K-25 Site Office oversight for the equipment removal projects within K-33.

The Oak Ridge K-25 Site Office did not guide oversight/monitoring of the converter removal work at K-33.

Because of widespread differing perceptions of responsibility expressed by various levels of OR management, it was not clear that any OR organization assumed responsibility for the K-33 converter removal work. These unclear lines of responsibility do not meet the Department's integrated safety management policies and principles, and they demonstrate that line management responsibility for the project was not assumed by OR.

Lockheed Martin Energy System Roles and Responsibilities

On January 6, 1997, LMES Environmental Management and Enrichment Facilities implemented comprehensive **organizational changes** based on four subordinate organizational components: Program Planning and Integration; Project Execution; Business, Financial and Subcontract Management; and Project Support. The organizational structure reflected OR plans to implement a matrix approach to project and safety management. These changes also responded to reduced resource levels, both realized and expected, which were anticipated to result in more efficient and effective work execution by matrixing needed resources to the projects. The converter removal work in K-33 was managed by Project Support.

OR line management did not assume responsibility for safety.

Interviews with senior LMES management revealed that the normal **process for project definition and execution** was expected to formally follow from the OR Assistant Manager for Enrichment Facilities to LMES Project Execution, which would task LMES Project Support. This was not the case for the converter removal work in K-33. In fact, the process flowed from the OR Assistant Manager for Enrichment Facilities directly to LMES Project Support.

The **specific process** employed to communicate work scope, schedule, and project details of the converter removal work in K-33 was generally informal. Existing LMES policies and procedures did not address specific details for "work for others" projects, nor did they provide the detail necessary to clearly and unambiguously establish roles, responsibilities, and lines of authority to interface with other necessary disciplines and crafts. The sequence of planning and requisite level of interaction with and feedback from others in the organization could not be discerned by reviewing documentation for the work at K-33.

The normal LMES process for project definition and execution was not followed.

The intricate **organizational interrelationships** in LMES established in January 1997 were being initiated and communicated to those affected at the time of the accident. Many of those affected, who had management responsibility for the activities that led to the accident, were unsure of their responsibilities at the time of the accident investigation. Since the January 1997 reorganization, functional roles and responsibilities were not understood below the LMES Oak Ridge Site Management Office (K-25) level. An additional factor involves job security concerns expressed during interviews by a significant number of LMES employees. LMES and K-25 have undergone significant reductions in the labor force, resulting in a decreased core competency base and experience level;

additional reductions are ongoing. The January 1997 reorganization resulted in a number of personnel assigned to new roles with unclear line, administrative, and project reporting lines and authorities, resulting in general confusion as to their specific responsibilities for project work. Further, as part of its reindustrialization efforts, DOE is negotiating with a consortium led by British Nuclear Fuels Limited and Manufacturing Sciences Corporation to take control of three large process buildings (including K-33) for decontamination and equipment salvage. The role of LMES and the potential fate of its employees in this effort are not clear.

LMES reorganization led to lack of clarity in roles and responsibilities.

These changes caused unclear or insufficient understanding of LMES line management **safety oversight** roles and responsibilities, including those for project planning and management and for oversight of the work. Consequently, first- line supervisors, safety personnel, and crafts employees may have assumed risks in the absence of clear direction and oversight by their managers. For example, inspection and evaluation of the actual work site inside Cell 7 by responsible supervision and safety personnel (who did not understand they had such responsibilities) were not adequately performed prior to and during the work. Except for health physics, there was no safety and health oversight of the work.

Senior **Project Support** management informally assigned the Manager of External Customer Projects as Project Manager for the K-33 converter removal work. The Project Manager understood his role to be that of a "coordinator" or "facilitator," responsible for maintaining customer satisfaction. Responsibility for budget and schedule was clearly understood; however, safety and health responsibilities were not. The Project Manager assigned a technical assistant as the Issuing Authority. In this role, the Issuing Authority is expected to perform the details of scoping, creating the Maintenance Job Request to initiate the work and obtaining the SWP and Burning Permit. However, these roles were dispersed among the planning organization, the maintenance organization, and the Service Supervisor. Thus, there was no single focal point who was responsible for and/or knowledgeable of all activities involved in the work.

Safety oversight within LMES was inadequate.

The **planning** organization, after cycling through several different planners for the converter removal work as a result of downsizing, finalized the Maintenance Job Request on January 27, 1997. The planners categorized the activity as "routine maintenance" and decided that no additional instructions were needed. The package was accepted by the Service Supervisor in the maintenance organization, who executed the work using welding and maintenance

Responsibility for and understanding of the work at K-33 were dispersed within the LMES organization.

mechanics. He had no prior experience supervising welders. The Project Manager and Issuing Authority were not included in this effort; moreover, there is no evidence that their review/approval was solicited or provided regarding the adequacy of the work package or that they received copies of the final Maintenance Job Request.

With no apparent input from the Issuing Authority, planners also selected the safety disciplines needed to support the work and identified necessary permits. Interviews disclosed that both the planners and the Issuing Authority assumed that they were responsible for initiating the request for permits. The Issuing Authority also perceived that his responsibility was to assure that signatures were completed on the SWP, not to verify that safety disciplines had adequately performed inspections of the cell before signing the permit.

Planning decisions were made largely by people outside of project management and/or not experienced with the work.

The **role of an Issuing Authority** is also not clearly defined. A listing of Issuing Authorities (effective December 31, 1996) disclosed that at least nine organizations have personnel designated for this capacity, including the K-33 Building Operator and the K-33 converter removal work Issuing Authority. The SWP and Burning Permit procedures do not consider a lead organization for signing the permits as the Issuing Authority. Therefore, there was no clear understanding of the Issuing Authority concept by personnel involved in the converter removal project.

At the **worker** level, LMES management controls, planning activities, and completion of the converter removal work relied on a base level of skill, referred to as "skill of the craft," to perform work safely. However, there was no common understanding at LMES regarding the specific knowledge and skills represented by "skill of the craft." Further, there was no commonly acknowledged delineation between knowledge regarded as "skill of the craft" and that which should be regarded as job-specific or not "routine." The involved workers' experience with other equipment removals was not adequate to compensate for the insufficient safety management controls and assumption of risk by employees on the K-33 removal work: the Service Supervisor had no previous experience with supervising welding; one of the welders had no experience with converter removal; none of the workers for this job had been involved with the most recent similar work at the SSMRP; and this was the first time these welders had been required to wear this level of personal protective equipment while removing converters under the conditions found in Cell 7.

The involved workers lacked the experience to compensate for inadequacies in management controls.

Within LMES Project Support, the Surveillance & Maintenance

Operations for the D&D organization is **responsible for the K-33 Building**—that is, for ensuring that the building is adequately maintained in terms of authorization basis, system and component integrity, waste storage, OSHA compliance, and environmental requirements. Functionally, this organization assigns a Building Operator who is responsible for the building. The Building Operator for K-33 at the time of the accident had been on the job for approximately one month; the prior Building Operator for K-33 was terminated as a result of downsizing. Interviews and a review of records revealed that neither of these individuals nor their staff of operators were included in the planning or monitoring of the K-33 converter removal work. Although mid- and senior-level management expressed, during interviews, an expectation that building operators/operators would be involved in the job planning and monitoring of the work, this did not occur.

The responsible LMES building operator was new to the job and was not involved in work planning and monitoring.

LMES has promulgated an Occupational Safety and Health Program Description in SH-152PD. The program is based on five tenets: management leadership, employee involvement, worksite analysis, hazard prevention and control, and safety and health training. Expectations are clearly stated for these general areas and include line management accountability for safety and identification of workplace hazards through the preparation of a Job Hazards Analysis. Various other policies and procedures generally articulate line management responsibility for safety and health. Evidence indicates that specific line management responsibilities for the converter work in K-33 were never formally established and were neither effectively communicated nor understood by management and workers.

LMES line management responsibilities for the work were not established, communicated, or understood.

The facts surrounding this accident include a variety of **safety management system breakdowns** in work planning, hazard evaluation, communications, and establishment and implementation of adequate work controls. The inadequacies included many examples of poor procedural implementation, beginning with pre-job planning and continuing through the failure to assign a fire watch to the project on the day of the accident. For the K-33 converter removal work, management followup on their written commitment to safety has not been effective.

The **chain of line management** and the attendant safety and health responsibilities were not clear to project management, K-33 building operations, planners, or the Service Supervisor. From the safety and health perspective, project management relied on planners, and planners relied on safety and health disciplines; however, not all safety and health disciplines had interaction with project

LMES work planning, hazard evaluation, communication, and work controls were ineffective.

management. Also, none of these groups had interaction with K-33 building operations. No one person or group understood and/or functioned as the central point for managing the project; thus, there was confusion regarding who was responsible. Because there was no overall direction, voids in line management responsibility for safety occurred throughout the work planning process, culminating in the accident.

No one LMES person or group understood and/or functioned as the central point for managing the project from a safety perspective.

2.3 BURN TEST ON WELDER'S CLOTHING

Based on witness interviews, the Board was concerned about the relatively short time it took for the Welder's clothing to be consumed. Of particular interest to the Board were the following: (1) the possible effects of laundering on the anti-contamination clothing worn by the Welder, (2) the timeline from ignition to the point of extinguishing the flames, and (3) the possible insulating effect of multiple layers of clothing, as it may affect the wearer's sensation of heat from the fire.

To resolve the laundering issue and/or to determine whether any accelerants or hydrocarbon compounds were present in the clothing worn by the workers in K-33, material from new and used clothing was tested at the request of the Board. Mass spectrometer tests of the clothing were conducted by Southwest Research Institute, San Antonio, Texas. The results of these tests indicated that the blue general-purpose coveralls and the yellow anti-contamination coveralls were of normal flammability and that laundering affected the chemical constituents in the materials in only minute, insignificant quantities. No accelerants or abnormal amounts of organic materials were found.

Laundering was found to have had no effect on the flammability of the outer coveralls.

To answer the remaining questions regarding the flammability issues, the Board requested a burn test. This test was also conducted by Southwest Research Institute using mannequins dressed in new and used clothing matching that worn by the Welder on the day of the accident. The mannequins were dressed with one set of underwear, one set of 100 percent cotton blue general-purpose coveralls, two sets of 100 percent cotton yellow anti-contamination coveralls, and other clothing as described in Section 2.1.1.

A burn test was conducted to determine how fast the coveralls burned and how wearing several layers of coveralls would affect the wearer's ability to detect the fire.

Thermocouples were placed between clothing layers at various anatomical locations. An electric heat coil, simulating a piece of hot slag, produced ignition. The left leg of the outer garment was ignited (location of fire initiation was based on the Welder's communication with paramedics and witnesses after the accident), and temperatures were recorded while the mannequin was filmed,

using video photography, to correlate flame spread with recorded temperatures.

Wisps of smoke were noted in 8 to 12 seconds, and the first few flames were seen at 30 seconds. Examining the data, extrapolating between the surface temperature of the mannequin and that of a person's skin (70°F and 90°F, respectively), and recognizing that the change in temperature with time was the most important factor, it was apparent that a 20-degree adjustment of the temperature readings was necessary in assessing the time it took for the Welder to sense the heat of the fire. Therefore, assuming that a welder would recognize a 30°F increase in temperature as "hot" and 50°F as "abnormally hot," then 100°F and 120°F, respectively, on the mannequin skin surface would be the equivalent threshold for the welder. Using these assumptions, the test data indicated that the worker might suspect a clothing fire by sensing heat at the following post-ignition times:

	30-degree change	**50-degree change**
Mid-thigh	65 seconds	80 seconds
Knee-inside	75 seconds	90 seconds
Groin area	140 seconds	150 seconds

Observing the extent of the fire at the elapsed time of 80 seconds on multiple mannequin test runs shows that containment or eradication by the Welder alone would be doubtful, if not impossible. In the Board's judgment, at 90 seconds from ignition, the extent and speed of the fire could only be controlled with fire- extinguishing equipment (e.g., fire blankets, fire extinguishers). Therefore, even if the worker felt the heat of the fire as early as 65 seconds into the event, he/she would have only 10 to 25 seconds to put it out before outside help would be necessary to extinguish the fire. At 120 seconds, the clothed mannequin was totally engulfed along the center axis, both front and rear, from the knee to the face. The fire continued to grow, and by 145 seconds, the shoulders and the clothing hood were in flames. A review of the test simulation videos shows approximately 90 to 95 percent of the clothing consumed in about 3½ to 4 minutes from ignition. This is consistent with the actual fire involved in the accident (see Exhibit 2-4, Remnants of the Welder's Burned Coveralls).

The test showed that by the time the wearer could feel the heat of the fire, he would not be able to extinguish it himself.

Exhibit 2-4. Remnants of the Welder's Burned Coveralls

It is important to note that the tests performed do not, and could never, actually duplicate the accident scenario that evolved at the accident scene. For example, the test was performed on a static mannequin, but much faster burn rates would be expected if the tests simulated a person in motion (running), thereby further ventilating the fire.

The outer anti-contamination coveralls do not provide protection from fire.

Results of the burn tests revealed that very high temperatures were attained quickly on the outer layers of the anti-contamination clothing, while the temperature at the skin level remained nearly the

same. The multiple layers of clothing effectively insulated the Welder from the heat and seriously impaired early detection of the fire. The burn tests also indicated that the anti-contamination and general-purpose coveralls worn by the Welder and other K-25 LMES welders did not, by themselves, provide any fire protection as personal protective equipment for the hazards of cutting, welding, and other hotwork. The flammability characteristics of the anti-contamination clothing made this clothing inappropriate for the cutting and welding operations being conducted at the time of the accident.

The Board determined that although the variables in a simulated test such as this are many and preclude precise measurement of the time

the Welder sensed the heat of the fire, the information from the simulation tests provides reasonable insight about the short time the Welder had to identify the fire and put it out before it became uncontrollable. Once this brief response window slipped by, only help from another worker, a fire watch, could have altered the outcome.

Administrative, management, and physical barriers were examined.

2.4 BARRIER ANALYSIS

A barrier is defined as anything that is used to control, prevent, or impede process or physical energy flows and that is intended to protect a person or object from hazards. The barrier analysis conducted by the Board addressed three types of barriers associated with the accident: administrative barriers, management barriers, and physical barriers. These barriers either failed or were missing. Successful performance by any of these barriers would have prevented or mitigated the severity of the accident. The barriers that failed are summarized in Figure 2-3. Appendix B provides details of the analysis.

Administrative barriers that failed are Job Hazards Analysis, work planning, and training.

Administrative Barriers

Safety staff did not perform a Job Hazards Analysis to ensure that hazards associated with the work activities were identified and evaluated, as required by LMES procedures and instructions. That is, the SWP process was not followed in its entirety for the work. Because converters had previously been removd in K-33 during the 1980s and more recently at K-31 for the SSMRP, management and participants in the work planning process considered this to be a routine activity; therefore, a Job Hazards Analysis (including onsite inspection) and work plan were not developed. The Burning Permit was improperly completed and

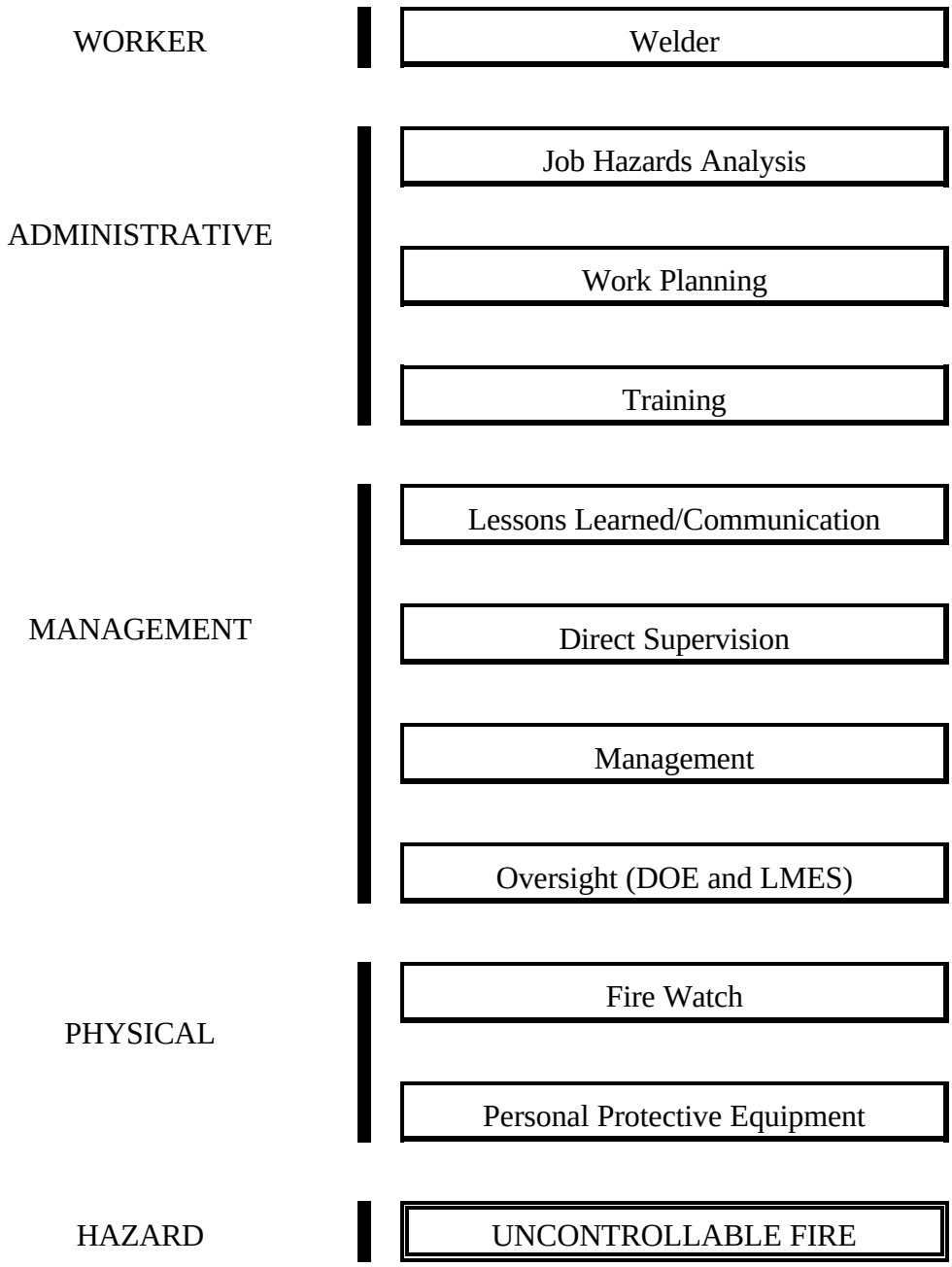

Figure 2-3. Barriers That Failed

was not validated, and a fire watch was not designated on the Permit. The Service Supervisor was not experienced, nor had the Issuing Authority for the permit or the Service Supervisor been trained in the Burning Permit process.

Management Barriers

Management barriers that failed are communication of lessons learned, direct supervision, management, and oversight.

Lessons learned from similar work activities and accidents were not incorporated into the work planning by planners, management, supervisors, or workers who prepared and carried out this work package. Precursors to this accident were not reported or communicated to management. Management was unaware of the fire hazard that existed, because employees were reluctant to report incidents and near misses. In addition, lessons learned from other work activities were not communicated effectively.

Supervision did not ensure that the workers understood safety requirements for the work, nor did they adequately verify that safe work processes were being implemented at the job site. A pre-job safety meeting with all people involved was not conducted. Lack of supervision for the work activity at the time of the accident was a failed barrier.

Reorganization of LMES and DOE, as well as their changing missions, changed the roles, responsibilities, and authorities of management to the extent that they were not clearly communicated or understood. Thus, important management and oversight barriers were less effective. The safety management processes failed because appropriate levels of management were not aware of the work being performed, nor did they understand their own roles and responsibilities below the senior management levels. Processes in place to ensure worker safety were not carried out or used effectively, and the normal oversight processes were not implemented.

Physical Barriers

Physical barriers that failed are fire watch and personal protective equipment.

Although required, no fire watch was assigned on the Burning Permit, and the Welder was alone at the time of the accident. In addition, the Department's requirements for a fire watch did not emphasize personnel protection. The personal protective equipment required by the Radiological Work Permit consisted of multiple layers of anti-contamination clothing and a full-face respirator. This selection of multiple personal protective clothing actually created a safety hazard. Non-radiological safety hazards were not considered when the determination for personal protective equipment was made as required by LMES safety policy. None of the three layers of clothing provided to and worn by the Welder were fire-retardant.

The clothing burned rapidly, and the multiple layers acted as insulation, reducing the Welder's ability to detect the fire. The Welder's mask and respirator also limited his ability to sense fire on his person.

2.5 CHANGE ANALYSIS

A change analysis was conducted to determine changes or differences that may have contributed to the accident. The results of the analysis are provided in Table 2-1.

Table 2-1. Change Analysis

Change or Difference		Analysis	
Planned/Normal	**Present**	**Difference**	**Analysis**
Job Hazards Analysis is performed for each job by interdisciplinary/ integrated team, and personal protective equipment is selected based on all hazards of the job.	No integrated Job Hazards Analysis was performed for this job, and personal protective equipment was selected without coordination by all safety disciplines.	Hazards for the work were not identified.	Failure to identify all hazards and appropriate personal protective equipment contributed to the accident.
Dedicated fire watch is assigned on all Burning Permits.	No fire watch was designated on the Permit.	No personnel were assigned to provide protection to the welders by observing fires either on welders or in the work area in the cell.	The absence of a fire watch was a factor in the accident.
Safety personnel perform a walk-through and evaluate the work area to determine the hazards prior to preparing the SWP.	Applicable safety disciplines did not perform a walk-through and inspection of the work area prior to preparing the Permit.	Safety personnel did not know the current condition of the cells and the inherent hazards of the job.	The lack of a thorough evaluation of the work area in the cell to identify hazards and safety measures (e.g., lighting, access/egress, fire extinguishers, communications) and subsequent provision of appropriate worker protection by safety personnel may have contributed to the severity of the accident.
Employees report injuries and near misses to their supervisors.	Employees did not report injuries or near misses.	Not all injuries or near misses were being reported.	Hazardous conditions were not known by management and continued without corrective action being taken.

Table 2-1. Change Analysis (Continued)

Change or Difference		Analysis	
Planned/Normal	**Present**	**Difference**	**Analysis**
DOE and LMES safety and health personnel are assigned to provide periodic observation and oversight of the work activities as part of line management oversight.	No safety and health personnel were assigned to observe the work activities, and there was no LMES or DOE oversight, except for the health physics organization.	There was inadequate safety and health oversight of the work.	Line management oversight did not adequately assure that safety requirements were implemented.
Supervisors are experienced, trained, and effective in communicating safety goals to the workers.	The Service Supervisor was not experienced, trained, or effective in communicating safety goals to workers.	The Service Supervisor did not have knowledge of all the safety requirements for the work and did not communicate the requirements to the workers.	The Service Supervisor was not aware of requirements for all the permits involved, did not supervise welders prior to this work, and did not communicate safety precautions for all aspects of the job to the different crafts.
Workers perform welding/cutting operations in K-33 Building while wearing normal work coveralls.	Workers had only recently begun to remove converters under the new requirements and conditions associated with radiological personal protective equipment requirements, which require multiple layers of anti-contamination clothing.	Workers were not experienced in working in multiple layers of personal protective equipment (e.g., anti-contamination clothing, full-face respirator).	Workers and supervisors did not identify or fully understand the additional risks created by the multiple layers of personal protective equipment (e.g., anti-contamination clothing, full-face respirator, and welder's mask).
Site operating under normal conditions without downsizing or mission transition.	Site operating in a downsizing mode with changing missions and decreased morale.	Fewer experienced and knowledgeable personnel, high stress, low morale, new mission and responsibilities.	Workers, supervisors, and management were distracted, and the core competency base of the workforce was shrinking due to the turnover, transition, and downsizing.

2.6 CAUSAL FACTORS

The root causes of the accident were lack of flame-retardant protective clothing and lack of an effective fire watch.

The **root causes** of the accident (the fundamental causes that, if eliminated or modified, would prevent recurrence of this and similar accidents) were (1) personal protective equipment worn by the Welder was not identified as a hazard (i.e., the personal protective equipment was not flame-retardant) and (2) personnel safety responsibilities for the fire watch were not appropriately emphasized. The combination of these causal factors was the primary reason the Welder (working alone) was susceptible to a fire hazard from the cutting/welding operations he was performing at the time of the

accident. Because protective barriers for the hazard were not in place, the fire became uncontrollable, and the Welder was unable to extinguish it alone.

These root causes, if eliminated or changed, would not only prevent recurrence of this accident at other DOE sites, but also, if eliminated on the day of the accident, would have prevented the accident. It is recognized that, analytically, both of these root causes could be taken to a higher level (i.e., the policy level within DOE, Federal regulations, and LMES K-25 policies, which do not specifically address either of the concerns). The Board believes that presenting the root causes at this higher level will not be helpful to those in the field who have to implement lessons learned for this accident. Stating the root causes more directly emphasizes the true nature of the accident's causes. However, the Board has taken the issue of specificity in policy into account in constructing the judgments of need.

The issue of specificity in policy was also considered in developing judgments of need.

There were also **contributing causes** (causes that increased the likelihood of the accident without individually causing the accident, but that are important enough to be recognized as needing corrective action). The causal factors are identified on Table 2-2, with a short discussion for each factor.

Table 2-2. Causal Factors Analysis

Root Causes	Discussion
Personal protective equipment was not identified as a potential hazard (i.e., the personal protective equipment was not flame-retardant).	Federal regulations, DOE Orders/rules, and LMES K-25 policies do not identify the need or requirements for flame-retardant personal protective equipment for welding/cutting operations. The Board believes that if the anti-contamination clothing worn by the Welder had been treated with a flame retardant, the fatality would not have occurred.
Personnel safety responsibilities for the fire watch were not appropriately emphasized.	Federal regulations, DOE Orders/rules, and LMES K-25 policies do not address personnel safety protection as a responsibility of the fire watch. If a fire watch had been present, with clear responsibilities for personnel protection, the Board determined that, even without flame-retardant clothing, the fatality would not have occurred.
Contributing Causes	**Discussion**
Multiple levels of personal protective equipment created an additional hazard.	The use of multiple layers of clothing resulted in a bulky garment package with many folds and creases that could capture sparks or molten slag. These layers of clothing produced an undesired insulating effect and reduced the Welder's ability to recognize (by sensing heat) that he was on fire. In addition, the respirator and welding mask impaired the Welder's peripheral vision and sense of smell. The Board believes that the amount of personal protective equipment worn increased the Welder's risk from a fire hazard and contributed to the accident.

Table 2-2. Causal Factors Analysis (Continued)

Contributing Causes	Discussion
Lack of reporting of clothing fires contributed to incomplete hazard recognition.	Previous clothing fires had occurred but had not been reported to management. Although workers are required by LMES procedures to report all safety concerns to their supervisors so that management may be aware of such safety issues, the Board believes that workers' acceptance of the risk and their fear of losing their jobs due to recent downsizing and reorganizations may have resulted in these safety issues not being reported. In addition, management did not foster an atmosphere that encouraged reporting of incidents. The Board believes that because the incidents were not reported, management did not have sufficient data to understand the hazard and take appropriate action.
LMES failed to: (1) adequately plan the work, (2) provide adequate procedures, and (3) implement existing procedures.	The requirements of the work planning process were not adequately implemented; the work was classified as "routine maintenance" within the "skill of the craft," even though the workers had no recent experience in converter removal. The work involved a variety of personnel hazards and had not been performed on a routine basis since 1985. A Job Hazards Analysis was not performed. The existing work permitting process was also not followed. The hazard controls did not address all hazards present at the work site. Work planning processes, including a Job Hazards Analysis, work plan, and pre-job safety meeting, should have been performed.
Line management responsibility and accountability for safety were not adequately defined for OR and LMES.	Management failed to ensure that workers and supervisors were properly qualified and trained to perform assigned tasks and that appropriate roles and responsibilities for safety were established and communicated. The Board believes that the lack of clearly defined roles and responsibilities for safety contributed to the accident.
Due to lack of oversight by OR and LMES, the opportunity to identify the hazard was missed.	There were no assessments and direct observations of the job by management, safety personnel, or DOE. The Board believes that had there been some oversight by the health and safety organizations or by the project management organizations (e.g., supervisor), the numerous clothing fires might have been observed and corrective actions taken.

3.0 CONCLUSIONS AND JUDGMENTS OF NEED

Conclusions are a synopsis of those facts and analytical results that the Board considers especially significant. Judgments of need are managerial controls and safety measures believed necessary to prevent or mitigate the probability or severity of a recurrence. They flow from the conclusions and causal factors and are directed at guiding managers in developing followup actions. Table 3-1 summarizes conclusions of the Board and judgments of need regarding managerial controls and safety measures necessary to prevent or mitigate the probability of a recurrence.

Table 3-1. Conclusions and Judgments of Need

CONCLUSIONS	PROPOSED JUDGMENTS OF NEED
The selection of personal protective equipment failed to consider the potential hazards (e.g., fire) associated with the use of anti-contamination clothing during welding, burning, and hotwork operations.	There is a need for the Assistant Secretary for Environment, Safety and Health (EH-1) to review and issue, as appropriate, policy and standards that include requirements for flame-retardant anti-contamination clothing and personal protective equipment worn by workers conducting cutting, welding, and other hotwork operations. Concurrent with the EH-1 review, LMES should review and revise, as appropriate, its specifications for anti-contamination clothing to determine the need for including flame-retardant requirements for the clothing which is worn by workers during welding/cutting/hot- work operations.
The combination of multiple personal protective equipment (which restricted sensory perception), flammable anti-contamination clothing, and the absence of a dedicated fire watch significantly reduced the protective barriers against fire hazards.	There is a need for EH-1 to review and develop appropriate requirements similar to 29 CFR 1910.120, Appendix C, for all DOE work activities to emphasize that personal protective equipment can, by itself, create significant worker hazards, and that overprotection, as well as underprotection, should be avoided where possible. Concurrent with the EH-1 review, LMES needs to evaluate safety hazards for workers specific to each job and the risks that may be added by use of multiple controls or personal protective equipment, in accordance with the requirements in the LMES K-25 Site Radiological Control Manual. There is a need for EH-1 to review and revise existing DOE policy regarding the responsibilities of fire watches to ensure that both worker safety and property loss prevention are considered. Concurrent with the EH-1 review of fire watch policy, LMES needs to review and revise, as appropriate, its fire watch program, procedures, and training to clearly identify that: • Fire watch responsibilities include both worker safety and property loss prevention, • Fire watches must always be in a position to detect a fire and provide adequate emergency response for the worker, and • Fire watches must be trained in appropriate response and provided with appropriate fire protection equipment (e.g., extinguishers, blankets, radios) that is immediately accessible and available for use.
The burn test conducted at the direction of the Board confirmed that the clothing worn by the Welder burned quickly and that the multiple layers of clothing insulated him from sensing the heat of the fire, seriously precluding his ability to extinguish the fire by himself.	None.

Table 3-1. Conclusions and Judgments of Need (Continued)

CONCLUSIONS	PROPOSED JUDGMENTS OF NEED
Precursors (e.g., near-miss clothing fires) occurring during welding and cutting operations similar to this accident were not recognized as safety hazards and reported.	There is a need for OR and LMES to foster and assure a work environment (including positive incentives) in which workers will report injuries and near-miss incidents through supervision to management.
The LMES planning process for the K-33 converter removal work did not ensure that an adequate Job Hazards Analysis was completed before work started. Therefore, controls to mitigate all the work hazards were not developed or implemented. Failure by LMES to provide adequate procedures and to effectively implement those in place prevented a clear understanding of expectations and the associated requirements for the work on the day of the accident. Lessons learned from previous and similar activities were not adequately evaluated, documented, or incorporated by LMES into the work planning for the K-33 converter removal work.	There is a need for LMES to strengthen existing work planning processes, including procedures and training, to ensure: (1) existing LMES instructions are used for performing a Job Hazards Analysis, which includes the identification of hazards and controls with each step of the work to be performed; (2) pre-job safety meetings are conducted with crafts people performing the work, appropriate safety personnel monitoring the work, and supervisors present; (3) clear criteria are established for work categories (e.g., routine, non-routine) that are based on the hazards and complexity of the work to be performed; (4) lessons learned are integrated into work planning and communicated to all project personnel; and (5) adequate supervision of the work. There is a need for LMES to clearly define in the Safety Work Permit Procedure that the Issuing Authority has the responsibility to assure that a Job Hazards Analysis is prepared in accordance with LMES instructions.
Neither the service supervisor who signed the Burning Permit nor the Issuing Authority, who also should have signed the Burning Permit governing the work activities, was trained in the importance of designating a fire watch and documenting it on the Permit.	There is a need for LMES to clarify the roles and responsibilities of K-25 issuing authorities, service supervisors, and other first-line supervisors relative to requirements, expectations, and understanding of the permitting process. There is a need for LMES to assure that issuing authorities, service supervisors, and other first-line supervisors at K-25 are adequately trained and have the requisite skills and knowledge to carry out their responsibilities in the work-planning and control process.
OR personnel below the first level of management involved in the K-33 converter removal “work for others” activity did not have clear expectations and understandings regarding their responsibilities and authorities for safety.	OR needs to ensure that roles, responsibilities, and authorities for management and safety are clearly defined, understood, and implemented at all levels by personnel (including those at site offices under OR cognizance) involved in planning, monitoring, and oversight of “work for others” projects.
LMES personnel below the Oak Ridge Site Management (K-25) level involved in the K-33 converter removal “work for others” activity did not have clear expectations and understanding regarding their responsibilities and authorities for safety.	There is a need for LMES to clearly communicate roles, responsibilities, and authorities for safety and oversight through all organizational levels, including line management and staff.

Table 3-1. Conclusions and Judgments of Need (Continued)

CONCLUSIONS	PROPOSED JUDGMENTS OF NEED
LMES has not effectively implemented its written commitment that line management is responsible for safety. Downsizing, organizational changes, and procedural inadequacies have created voids in line management, resulting in the absence of overall direction and a single focal point for the K-33 converter removal work who would be responsible for and knowledgeable of all activities involved.	LMES needs to put its written commitments into action, implementing a safety management system that establishes clear accountability for safety throughout all levels of the organization.
The overall quality of the accident response, even considering the lighting and egress problems, was satisfactory and provided the Welder opportunity for survival, had the burn wounds not been so extensive.	None.

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4.0 BOARD SIGNATURES

_____ Date: _____

Fred J. Volpe
DOE Accident Investigation Board Chairperson
U. S. Department of Energy
Office of Environment, Safety & Health

_____ Date: _____

Robie L. Monroe
DOE Accident Investigation Board Member
U. S. Department of Energy
Office of Environment, Safety & Health

_____ Date: _____

Carl A. Caves, P.E., C.S.P
DOE Accident Investigation Board Member
U. S. Department of Energy
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Randall C. Smyth
DOE Accident Investigation Board Member
U. S. Department of Energy
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_____ Date: _____

Charles T. Williams
DOE Accident Investigation Board Member
U. S. Department of Energy
Oak Ridge Operations Office

_____ Date: _____

Craig H. Booker
DOE Accident Investigation Board Member
U. S. Department of Energy
Oak Ridge Operations Office

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5.0 BOARD MEMBERS, ADVISORS, AND STAFF

Chairperson	Fred J. Volpe, DOE, EH-24
Member	Robie L. Monroe, DOE, EH-24
Member	Randall C. Smyth, DOE, EM-46
Member	Charles T. Williams, DOE, Oak Ridge
Member	Craig H. Booker, DOE, Oak Ridge
Member	Carl A. Caves, DOE, EH-22
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Advisor	Dennis Kirson, DOE, Albuquerque
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Administrative Support	Barbara S. Harshman, DOE, EH-21
	Elizabeth A. Curtiss, Battelle Columbus
	Charlotte Textor, Battelle Oak Ridge

APPENDIX A

APPOINTMENT MEMO FOR TYPE A ACCIDENT INVESTIGATION

APPENDIX B

PERFORMANCE OF BARRIERS

Appendix B. Performance of Barriers

Barrier	Purpose	Performance
Work Planning	To develop the work activities, identify and evaluate hazards, and establish safety practices for the work to be performed.	Barrier failed because the work was considered "routine," and no Job Hazards Analysis or work plan was developed.
Job Hazards Analysis	To identify hazards associated with the work activities and evaluate and specify health and safety requirements, as required in LMES pro- cedures, instructions, and permits related to work planning.	Barrier failed because coordinated, interdisciplinary inspection and evaluation was not performed to recognize the hazards for the work activity.
Training	To ensure that personnel involved with certain activities are cognizant of the job requirements, procedures, permits, and safety practices required to perform tasks safely.	Barrier failed because training was not required for the Service Supervisor and Issuing Authority on the Burning Permit process; therefore, they did not understand the process and the impor- tance of assigning a fire watch.
Lessons Learned/Communication	To provide information from similar work activities or previous accidents to ensure that hazardous situations can be identified and avoided.	Barrier failed because the lessons learned from previous, similar work were not used by management in the K-33 work. Workers were not reporting injuries and near misses.
Direct Supervision	To provide direction to workers and monitor their activities.	Barrier failed because supervision did not under- stand its role, provide direction, and discharge its responsibilities in monitoring work activities.
Management	To assure that there is a structured and integrated safety management system with clearly defined roles, responsibilities, and authorities for safety.	Barrier failed because management responsi- bilities for safety were poorly defined, not communicated, and not understood. As a result, clear and rigorous safety processes and practices were not in place, not understood, or not followed.
Oversight (OR and LMES)	To assure that project work is accomplished safely in accordance with applicable require- ments.	Barrier failed because responsibility for safety oversight was not understood or implemented.
Fire Watch	To provide a trained individual who is dedicated to observing welding, burning, and hotwork activities for the purpose of providing an additional level of protection from hazards.	Barrier failed because no fire watch was assigned. Policy for fire watch does not place emphasis on personnel protection.

Appendix B. Performance of Barriers (Continued)

Barrier	Purpose	Performance
Personal Protective Equipment	To protect workers from hazards associated with specific jobs and work activities.	Barrier failed because personal protective equipment selected was not fire-retardant. Federal regulations, DOE Orders/rules, and LMES K-25 policies were not established for fire-retardant materials. Multiple layers of equipment provided loss of sensitivity (sight, smell, feel) to fire/heat.