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ENVIRONMENTAL RESTORATION PROGRAM

Environmental Health and Safety Independent Investigation of the In Situ Vitrification Melt Expulsion at the Oak Ridge National Laboratory, Oak Ridge, Tennessee

ENERGY SYSTEMS
ER

MANAGED BY
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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Energy Systems Environmental Restoration Program

Environmental Health and Safety Independent Investigation of the In Situ Vitrification Melt Expulsion at the Oak Ridge National Laboratory Oak Ridge, Tennessee

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LOCKHEED MARTIN ENERGY SYSTEMS, INC.
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The independent investigation team communicated with the ISV project personnel during the independent investigation and wishes to express appreciation to them, and to Mr. Brian Spalding, in particular, for their excellent cooperation.

APPROVALS

Environmental Health and Safety
Independent Investigation
of the In Situ Vitrification Melt Expulsion
at the Oak Ridge National Laboratory,
Oak Ridge, Tennessee
(ORNL/ER-371)

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PREFACE

This report, *Environmental Health and Safety Independent Investigation of the In Situ Vitrification Melt Expulsion at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, (ORNL/ER-371) was prepared in accordance with requirements specified in a letter of appointment from the director of the Environmental Restoration Division, Department of Energy-Oak Ridge Operations.

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ABBREVIATIONS

ASA	Auditable Safety Analysis
DBE	design-basis event
DOE	U. S. Department of Energy
dpm	disintegrations per minute
ER	Environmental Restoration Program
ES&H	environment, safety and health
FRT	Facility Readiness Team
HASP	health and safety plan
ISV	in situ vitrification
LMER	Lockheed Martin Energy Research Corporation
LMES	Lockheed Martin Energy Systems
MEE	melt expulsion event
OAT	Operational Acceptance Test
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
PNL	Pacific Northwest Laboratories
RRB	Readiness Review Board
WAG	Waste Area Grouping

EXECUTIVE SUMMARY

At about 6:12 p.m., EDT, on Sunday, April 21, 1996, steam and molten material were expelled from the Pit 1 In Situ Vitrification (ISV) project at the Oak Ridge National Laboratory (ORNL). This expulsion caused the off-gas collection hood to displace vertically and release hot pressurized steam. Molten material also flowed from beneath the hood. No personnel were injured or contaminated from this event, and no radioactivity exceeding surface contamination or air activity limits was detected outside the Hazardous Waste Operations and Emergency Response boundary. Radiation levels were sufficiently low that personnel external exposures did not approach administrative limits. Some damage to the hood and associated equipment occurred.

On April 26, 1996, at the request of the director of the Environmental Restoration Division of the Department of Energy in Oak Ridge, an independent investigation team was named to examine the environmental, safety, and health issues associated with the event and to issue a report within 45 days. The team interviewed ISV project personnel and others associated with the reviews and approvals of various project-related activities, reviewed project documents, and inspected the ISV site.

ISV technology has been in existence for a number of years with at least 100 melts occurring at various sites across the United States. In the 5 years prior to the melt expulsion event at ORNL Pit 1, there have been three melts at other sites that experienced a large expulsion of material.

The Health and Safety Plan (HASP) for the ISV project described these previous melt expulsions. Some preventive and partial mitigative measures were incorporated into the ORNL ISV project as a result of lessons learned from these previous expulsions. However, the HASP did not acknowledge a large melt expulsion event (MEE) as a design-basis event because the probability of its occurrence at the ORNL Pit 1 site was judged by the project team and the Pacific Northwest National Laboratory oversight committee to be remote considering the additional precautions that were taken and the characteristics of the site. The conclusion that the potential for an MEE was remote was not aggressively challenged by the safety analysis (HASP) or readiness review process.

During the conduct of operations prior to and during the melt at Pit 1, several preventive and mitigative measures that were committed to in the HASP were not fully executed in the field. No evidence was provided that a thorough evaluation was conducted of these variances before proceeding with the melt. However, the investigation team must note that there is no guarantee that the full incorporation of these measures would have prevented the MEE from occurring at Pit 1.

The investigation team makes the following two major recommendations:

- Acknowledge a large melt expulsion event as a design basis event in all aspects of the project, especially protection of on-site personnel.
- Improve the rigor of conduct of operations in the area of change control and the evaluation of variances from project commitments.

1. SCOPE OF THE INVESTIGATION

At about 6:12 p.m., EDT, on April 21, 1996, steam and molten material were expelled from the Pit 1 in situ vitrification (ISV) project at the Oak Ridge National Laboratory (ORNL). At the request of the director of the Environmental Restoration (ER) Division, Department of Energy-Oak Ridge Operations (DOE-ORO), an independent investigation team was established on April 26, 1996. This team was tasked to (1) determine the facts related to the ORNL Pit 1 melt expulsion event (MEE) in the areas of environment, safety, and health concerns such as the adequacy of the ISV safety systems; operational control restrictions; emergency response planning/execution; and readiness review and (2) report the investigation team findings within 45 days from the date of incident. These requirements were stated in the letter of appointment presented in Appendix A of this report. This investigation did not address the physical causes of the MEE. A separate investigation was conducted by ISV project personnel to determine the causes of the melt expulsion and the extent of the effects of this phenomenon. In response to this event, occurrence report ORO–LMES–X10ENVRES–1996–0006 (Appendix B) was filed. The investigation team did not address the occurrence reporting or event notification process.

The project personnel (project team) examined the physical evidence at the Pit 1 ISV site (e.g., the ejected melt material and the ISV hood), reviewed documents such as the site-specific health and safety plan (HASP), and interviewed personnel involved in the event and/or the project. A listing of the personnel interviewed and evidence reviewed is provided in Appendix C.

2. FACTS

2.1 SITE HISTORY

Chapter 3 of the *Site Safety and Health Plan (Phase III) for the Treatability Study for In Situ Vitrification at Seepage Pit 1 in Waste Area Grouping 7 at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, ORNL/ER–314, contains the following description of the site history.

Pit 1 was constructed in August 1951 by digging a 30 × 115 ft trench into weathered shale residuum to a maximum nominal depth of 15 ft. In the following 3 months, Pit 1 is estimated to have received 389 Ci of mixed fission products, about 200 Kg of depleted uranium, and 266 mg of plutonium. This radioactivity was introduced to Pit 1 as sludge suspended in ~ 123,000 gal of highly-alkaline liquid. This pit was a proof-of-principle operation and leaked into a nearby drainage soon after disposal began. Pit 1 was not used for routine disposal after 1951 but did receive additional discharges between 1962 and 1970 because the drain from Bldg. 7819 (a decontamination building) emptied into it. These discharges of acids, soaps, and chelating agents were not monitored, but since the decontamination activities involved contact-handled equipment, these discharges probably did not significantly add to the inventory of radioactivity in Pit 1. Pit 1 was covered with asphalt-coated corrugated metal sheeting to prevent infiltration of precipitation. An aerial of Pit 1 is shown in Fig. 1. The pit and surrounding areas have been surveyed for radiation fields and the maximum exposure rate was 10 mR/h at a location south and down slope of the pit, while rates over the pit range from 0.017 to 0.050 mR/h. Background exposure rates at uncontaminated locations on the Oak Ridge Reservation average between 0.010 and 0.017 mR/h.

2.2 IN SITU VITRIFICATION PROCESS

Chapter 5 of the HASP provides the following description of the ISV process. ISV is the process of converting contaminated soil into glass in place. This vitrification is accomplished by applying electrical power to a soil volume through graphite electrodes to melt the soil to the desired depth and width. This process minimizes personnel hazards because it is not necessary to excavate, handle, package or transport the contaminated soil.

Major equipment needed to conduct ISV includes the following six items:

- electrical power supplies,
- off-gas hood and High Efficiency Particulate Air pre-filter equipment,
- off-gas treatment system,
- glycol cooling system,
- process control station, and
- off-gas support equipment.

Normal operating hazards associated with these items are described in the HASP.

An organization chart of the Pit 1 ISV study is presented in Appendix D.

Fig. 1. Aerial of the in situ vitrification site—ORNL Pit 1.

2.3 GENERAL DESCRIPTION OF THE EVENT

On April 21, 1996, an MEE occurred as the first melt at ORNL Pit 1 was reaching the bottom of the pit. None of the four personnel present on site at the time were injured, and no transferable on-site radioactive contamination or radioactivity off the ISV site in excess of allowable limits was detected. Air monitoring results were negative except for radon daughters, which could not be confirmed to be a result of the event. Maximum on-site radiation levels were not high enough to warrant pulling personnel dosimetry. Some of the steel hood panels were deformed and several on-hood systems and supporting power and controls were damaged. The hood superstructure appeared to be undamaged.

The temperature of the molten material prior to the MEE was ~1500 °C. The melt was about 15 ft deep at the time of the event (electrode depths were 15.08 ft {SE}, 15.5 ft {NW}, 14.83 ft {NE}, and 13.42 ft {SW}) from starting grade. Starting grade was about 6.5 ft below the pit surface, which was about 3.5 ft below the original grade.

When the event occurred, the hood shell was observed to have broken its seal with the ground and lifted about 6–12 in. Figure 2 presents the time sequence of the event. On the north end, an emission of hot gas was observed, which resulted in the ignition of most combustible material in its path. This included several cardboard boxes (containing noncombustible materials) and vegetation on the graded slope of the pit 30–40 ft away. A section of fiberglass grating had been placed on the ground under the catwalk on the hood to act as a walkway across the muddy soil surface of the pit. According to ISV personnel, when this grating burned, it contributed to much of the damage to equipment on the north side of the hood. The damage may also be the result of hot gases expelled on the north side.

There is melt flow out from under the hood on the southeast side (Fig. 3). It extends out from the hood about 3–5 ft and is about 4–6 in. thick. On the south side, melted material flowed out of the east two-thirds of the hood, extending out 1–2 ft and is about 4–6 in. thick. Fiberglass grating was burned but did not cause damage similar to that on the north side.

2.4 RADIOLOGICAL MONITORING

Extensive radiological monitoring was conducted before and after the MEE (Appendix E). Project personnel working at the time of the event did not receive any external or internal personnel contamination. This was confirmed through radiological monitoring of personnel immediately after the event and through whole body and bioassay monitoring.

A radiological survey of the area after the event indicated that no transferable contamination was detected on the hood, the roughing filter, or the surrounding areas. Smears were less than 200 dpm beta and less than 20 dpm alpha.

Radiation levels on and around the hood increased as a result of the radioactive material contained in the glass. Prior to the event, all radiation levels on and around the hood were less than 0.2 mR/h. After the event, levels at contact with glass increased to a maximum of 8 mrad/h on the southeast edge of the hood and ranged from 3.5 to 7.0 mrad/h on the south and west sides of the hood.

Some pieces of molten glass were ejected and typically read 15,000 to 20,000 dpm/100 cm^2 with a maximum of 30,000 dpm/cm^2 or about 3 mrad/h. The main hazard associated with these pieces is the thermal hazard if personnel were in the area during the ejection of the molten glass. These pieces ranged up to about 1 in. × 3 in.

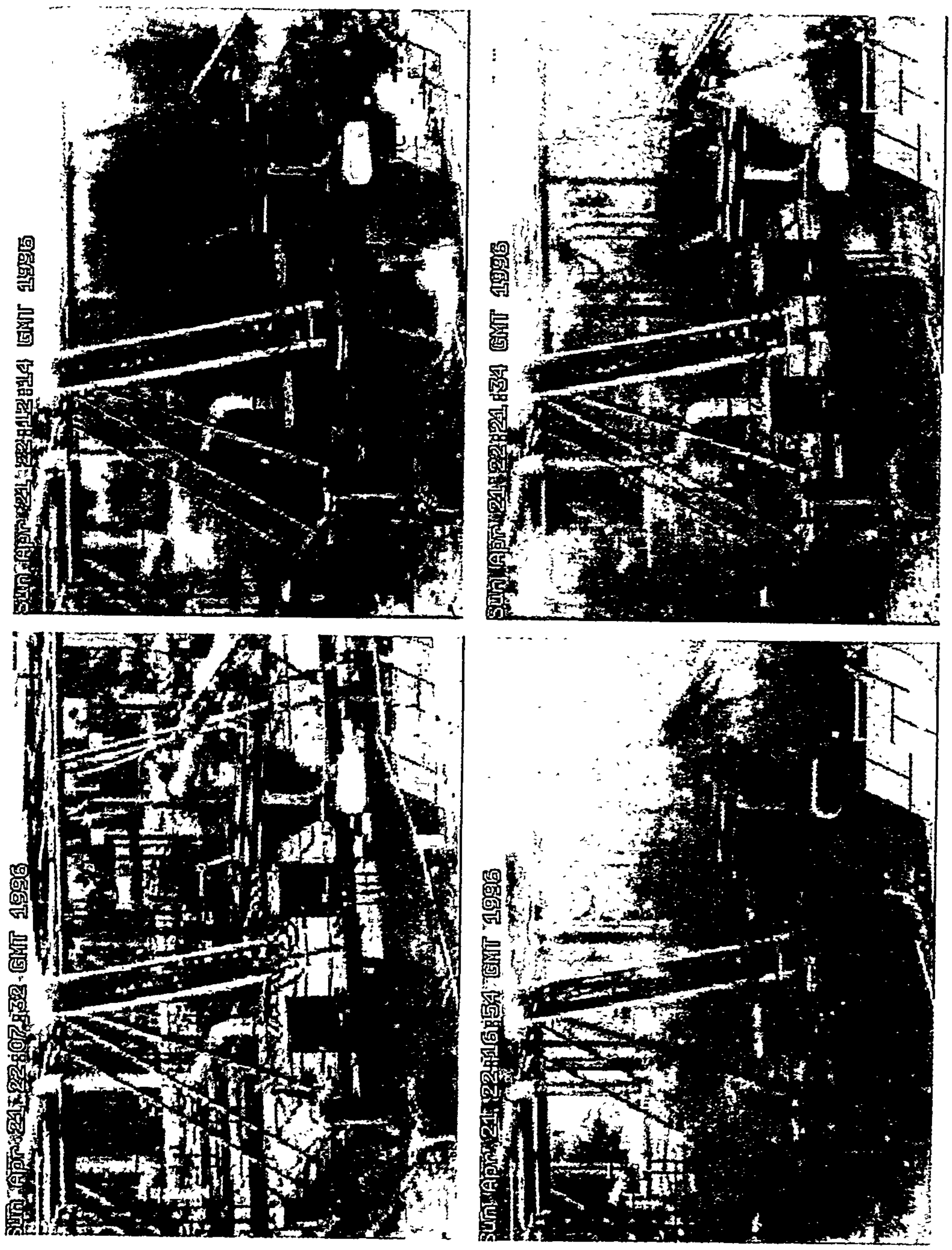


Fig. 2. Time sequence of the melt expulsion event at ORNL Pit 1.

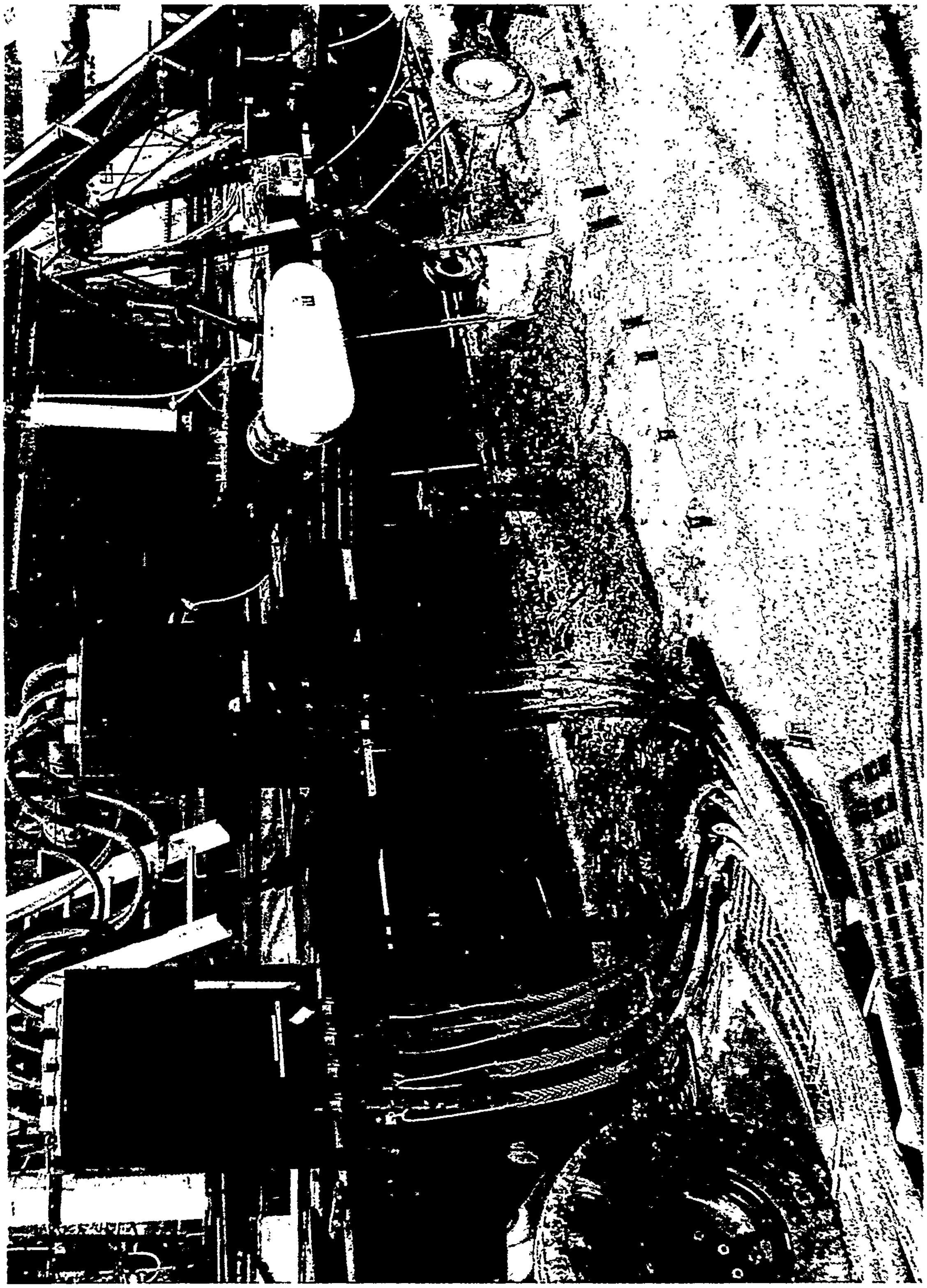


Fig. 3. Glass found on the southeast side of the melt expulsion event at ORNL Pit 1.

Radiological survey maps from April 20, 1996 through April 23, 1996, were compared to determine the changes in radiological conditions resulting from the event. Small pieces of solidified glass were found over and around the immediate site (50 ft–100 ft). These pieces of "angel hair" (Fig. 4) did not exceed the surface contamination limits specified in the ORNL *Radiological Protection Procedures Manual*. Radiological Control personnel found many of these pieces by looking for them at night with a flashlight, rather than utilizing radiation detecting instruments. The radiation levels emitted by individual small pieces were too low to be detected using the instruments.

No airborne radioactivity other than radon daughters was detected after the event. It is not possible to determine if the event contributed to the radon detected, since radon daughters are naturally occurring and the levels vary greatly depending on the time of day and environmental conditions. Radiological surveys determined that there was no transferable contamination in excess of allowable limits inside the hood itself where accessible. This indicates that the probability of off-site airborne releases were negligible.

2.5 ISV TECHNOLOGY EXPERIENCE AND LESSONS LEARNED

Interviews with ISV project personnel and review of the HASP and other project documents revealed the following history of ISV technology.

ISV technology has been in existence for a number of years. Currently, there have been at least 100 melts at a number of sites in the United States. Of these 100 melts, the HASP describes three events during operations by Pacific Northwest Laboratory (PNL) or Geosafe Corporation where melt material was expelled similar to the incident that occurred at the ORNL Pit 1 on April 21, 1996. Studies evaluating these events and other potential accident scenarios have been performed to evaluate this technology experience, with emphasis on the potential causes of melt expulsions. Descriptions of the three expulsion events and their causes are included in the accident analysis section of the HASP.

The first ISV MEE occurred on March 7, 1991, during an operational acceptance test of ISV by Geosafe Corporation on a staged treatment volume containing twenty 55-gal drums of water-saturated soil. Molten soil was expelled from the melt onto the soil surface under the fiberglass off-gas collection hood. This incident also resulted in fire damage to the hood. The combination of fixed electrodes and sealed drums was believed to have contributed to the build up of a steam pocket and the ejection of the melt.

A second incident occurred on July 21, 1991, during a PNL large-scale test of ISV on a buried 6000-gal tank. This incident resulted in the off-gas hood being raised at least 12 in. off the ground and molten soil flowing over the original soil surface. A steel off-gas hood was used to avoid fire problems, but it suffered damage to several panels and aluminum port covers. The cause was ascribed to the sealing of the walls of the tank to the melt body precluding the normal pathway for dissipation of steam from the melt.

The third melt expulsion occurred in December 1994 during a Geosafe Corporation ISV operation on moist soil above a concrete floor. The melt appeared to contact the concrete floor in a manner that left no avenue for steam to escape except through the melt.

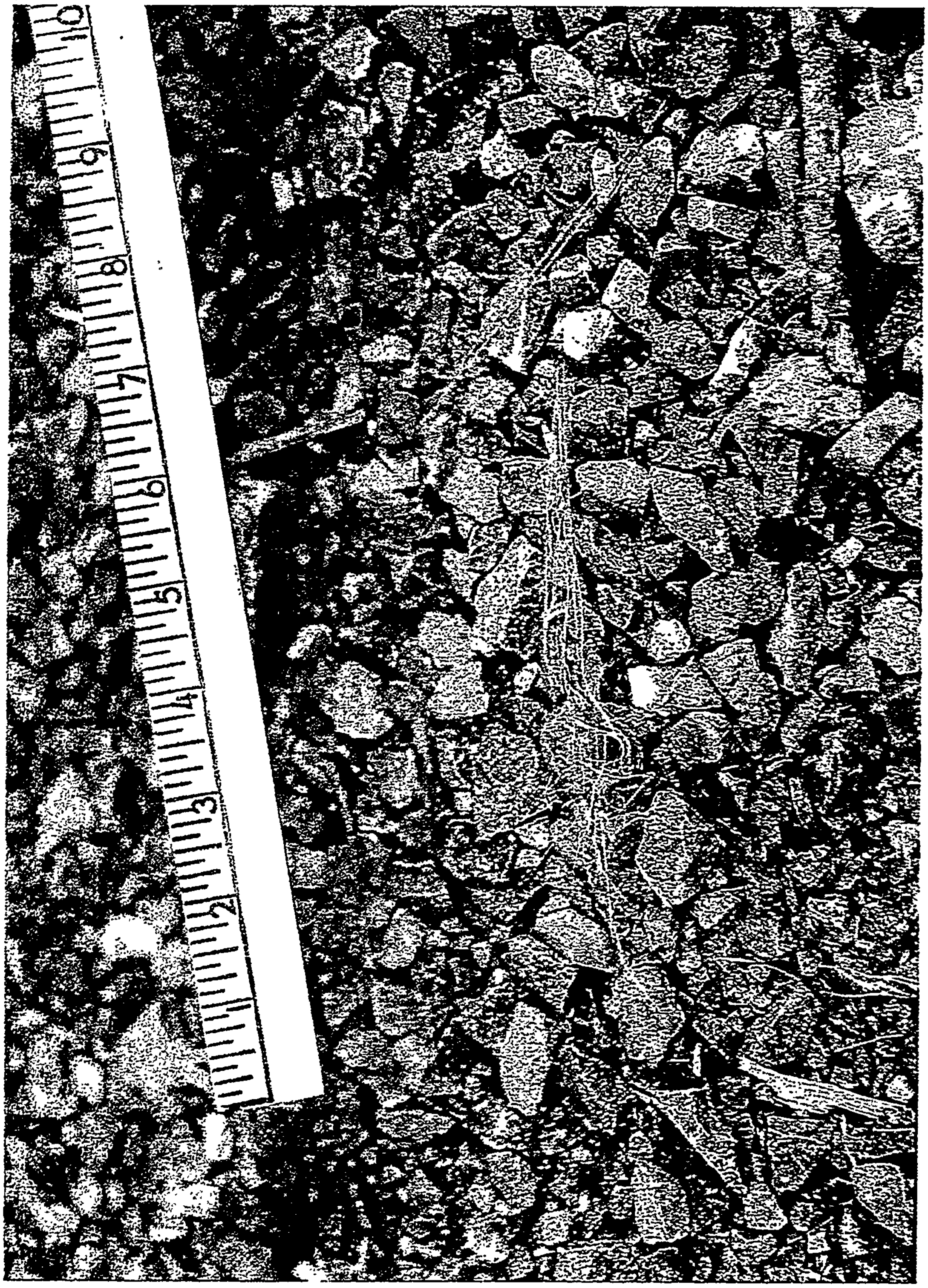


Fig. 4. Angel hair found at the melt expulsion event at ORNL Pit 1.

Project personnel indicated that the most common attribute of these events is that they occur near the end (bottom) of a melt when steam being created in the soil ahead of the melt does not have an adequate path to flow around the melt. The presence of underground structure (i.e., drums, tanks, floor) was believed by project personnel to have been the cause of constricting steam flow around the melt. Project personnel also indicated that the bubble, once formed, rises through the melt fairly rapidly and that no consistently reliable precursors to an MEE have been identified yet that could serve as advance warning in time to avoid the event.

There was no documentation of injuries to personnel in any of the three previous MEEs. Review of the investigative reports compiled on these events did not reveal that specific corrective measures were recommended to isolate or shield personnel from future potential MEEs. The ORNL ISV project incorporated several recommendations or lessons learned from the three previous MEEs into their design in an attempt to reduce the likelihood or consequence of an MEE (see Sect. 2.7).

In May 1994, at a site in Michigan, Geosafe completed nine large-scale ISV melts on saturated clay soil similar to ORNL Pit 1. Approximately 4800 tons of soil were processed without any expulsion events.

For several years, the ORNL ISV program has conducted preliminary characterization and scale melts in preparation for the full scale ISV on Pit 1. The program has cooperated closely with PNL ISV personnel, which are developers of the technique. Plans to begin the Pit 1 melt in the summer of 1995 were delayed due to a structural failure of the hood, which contributed to the project exceeding original budget and schedule expectations.

2.6 HAZARD EVALUATION

Chapter 7 of the HASP describes the project hazard evaluation and includes the analysis of several accident scenarios associated with the ISV project. In doing so, it goes well beyond the scope of a routine HASP and addresses issues (frequency and consequences of accidents) that are usually within the purview of the project safety analysis. The HASP was prepared by project personnel. The safety analyst contacted by the project manager noted that the hazard evaluation in the HASP appeared to meet the overall requirements of DOE-EM-STD-5502, "Hazard Baseline Documentation" for an Auditable Safety Analysis (ASA) for a radiological facility. These are to (1) identify hazards and (2) address the adequacy of measures taken to eliminate, control, or mitigate the identified hazards. The standard also allows for the ASA content to be integrated into the HASP. The safety analyst recommended that a separate ASA not be performed.

After describing the three previous MEEs, the HASP states in Sect. 7.2.2 that "the number of these expulsion events during ISV processing mandates considerable concern for application of ISV to ORNL Pit 1." The HASP addresses the influence of soil moisture and water content on ISV and concludes that "a true sealing, like the ISV melt body to steel drums or concrete walls . . . would not be possible between liquid water and molten soil." The HASP does not appear to address the possibility of rock strata underlying the pit ("Site Characterization Activities Summary for ORNL Seepage Pit 1 Prior to Its Use for In Situ Vitrification") acting as a restriction for steam flow around the melt. Measures taken by the ISV project to reduce the likelihood or consequences of MEEs will be discussed in this report.

A number of additional safety precautions relative to a potential pressurization event were identified in the HASP and the operating procedure. These included several modifications to the off-gas piping and the hood to allow for movement in the event that a pressurization event occurred. In addition, according to the HASP, "the safety zone to be set up around the hood during ISV operations would minimize the probability that personnel would be exposed to inadvertent contamination by radioactive gases during a hood pressurization event." The ORNL Pit 1 off-gas hood was constructed of stainless steel to minimize the potential for damage in the event of an expulsion. Flammable material was prohibited from the safety zone. However, some combustible materials such as fiberglass mats, plastic sheeting, cable insulation, and a few wooden items were located in the safety zone near the hood and were ignited by the hot gases during the event. According to event eyewitnesses, these fires from the combustible material accounted for most of the damage to equipment around the hood.

The project team leader stated that the project team and the Pacific Northwest National Laboratory oversight committee evaluated the previous technology experience for the causes of MEEs during ISV operations at other locations, implemented additional safety precautions to prevent or mitigate the possibility of an MEE, and considered the probability of such an event to be remote. As a result of their review and the incorporation of preventive measures, the project team did not consider an MEE to be a design-basis event (DBE).

The HASP implies that the lack of underground structures and the incorporation of additional preventive measures eliminate the large MEE as a credible event. This is evidenced by the omission of its effects from Sects. 7.1.4 "Pressure" and Sect. 7.1.9 "Thermal." No personnel protective measures were discussed for the pressure or temperature effects of a large MEE. The DBEs that were included focused on radiological consequences. In addition, per the "Design and Fabrication Procurement Specification for an In Situ Vitrification Off-Gas Hood System," Sect. 12.1.2.2, the maximum hood plenum design pressure was +0.5 in. w.c. which is much less than the pressure that would accompany a large MEE.

2.7 MELT EXPULSION EVENT PREVENTIVE AND MITIGATIVE MEASURES

Section 7.2.3 of the HASP states that "there are a number of attributes of the planned Pit 1 ISV melts which lead to a minimization of the potential for large melt expulsions or, at least, mitigating their impact." These attributes included vent pipes, a startup trench, a water spray suppression system, and in situ heating.

1. ***Vent pipes*** were installed prior to the melt to provide a relief path for pressure that may build up in the volume of soil beneath the melt. These pipes were perforated along their length and were vented into the hood. The vent pipes were driven into the soil volume at varying angles to intercept the melt at various elevations as the melt progressed downward. Since the vent pipes would be consumed as the melt progressed, vent pipes at different distances and angles were required to vent the soil at various levels where pressure might build up. The HASP stated in Sect. 5.2.4.2 that "only the lowest layer of vent screens will be positioned to survive the final melt depth . . ." The *Oak Ridge National Laboratory Pit 1 In Situ Vitrification Treatability Study* stated in Sect. 4.5.5 that ". . . as one level of vent pipes is overtaken by the melt, the next level should be active during the final portion of the melt setting." However, vent pipes were not installed at the expected lowest levels of the melt (probably the last 3 ft according to the project team leader), since the angle required would have placed the end of a straight pipe at a significant distance outside the off-gas hood and not allowed collection of the off-gasses. At the time of the MEE, the melt had progressed past the deepest vent pipe.
2. A ***startup trench*** 4–7 ft below grade level was cut to enable the ISV electrodes to penetrate to the bottom of Pit 1. In addition, it provided a safety factor if a melt expulsion were to occur

because it increased the buffer volume of the off-gas hood to pressurization and would contain any minor expulsions or flow from the melt zone. The trench was designed to prevent the soil from falling in on the melt as it dried out from rising heat.

3. The HASP states in Sect. 7.2.3 that a ***water spray suppression system*** was installed based on a "concept employed in nuclear reactor containment" which "works by injecting atomized water into the off-gas hood during a pressurization." As actually designed, the system held 30 gal of pressurized water which was to be automatically injected at about 3 gpm following high hood pressure. Project personnel stated that this system, as designed, would not mitigate a large MEE.

4. The HASP states that ***in situ heating*** prior to the melt to drive off excess water was to be considered for inclusion into the ORNL Pit 1 project depending on bench scale testing being conducted at PNL. Due to technical problems with the bench scale testing, in situ heating was not performed, according to project personnel.

None of these four preventive/mitigative measures were clearly identified as "safety systems" in the HASP nor was the continuous video monitoring mentioned as important in the HASP so identified. In fact, the HASP identifies in Sect. 5.2.3.2, "all safety-class items (e.g., handrails, steps, toe kicks.)" When questioned by the investigation team, neither the project team leader or the PNL project manager identified these four preventive/mitigative measures or the video monitoring as "safety systems."

2.8 READINESS REVIEW

A project Field Readiness Review Team (FRT) was established, and a readiness review plan was developed and approved. In addition, a DOE Readiness Review Board (RRB) was also established, and a DOE Readiness Review Plan developed. The composition of neither the FRT or RRB included an ISV subject matter expert not associated with the ISV project at ORNL or PNL. Not all members of the original RRB were active contributors to the process. The RRB that was reconstituted in March 1996 with several new members completed the readiness review process. During the process, the FRT and RRB met jointly to discuss concerns and evidence of closure.

Discussions with several members of both groups indicates that they discussed the potential for an MEE and the precautions taken to prevent or mitigate such an event. For example, evidence was provided that the design of the off-gas piping to accommodate some movement following hood displacement from pressurization was examined in the readiness review process. However, the review criteria in Table 1 of the *Readiness Review Plan for the In Situ Vitrification Demonstration of Seepage Pit 1 in Waste Area Grouping 7*, ORNL/ER-294, do not specifically examine the potential for a large MEE nor do additional criteria developed by the RRB. Little written evidence was provided documenting that the readiness review questioned the project decision not to include the large MEE as a DBE. Readiness review personnel stated that they accepted the judgment of the project personnel that the probability of an MEE was remote.

Evidence was provided from the readiness review that stated that indicating socks had been attached to all vent pipes before ISV operations commenced for the first melt.

2.9 CONDUCT OF OPERATIONS/CONFIGURATION MANAGEMENT

Socks were to be installed on the vent pipes at the surface so that video cameras could observe any inflation or deflection that would indicate gases escaping through the vents. Socks were not installed on all of the vent pipes, however, because several of the pipes could not be found due to backfill covering the pit during site preparation. The project team leader indicated that those vent pipes that were covered by backfill would still be expected to function as vents even though their functioning could not be observed.

Two video cameras were installed on the hood to observe and record the movement of vent socks and the behavior of the melt surface and the soil surrounding the melt for possible erosion or subsidence. One of these cameras was installed in the top of the hood looking down, and the other was installed in the side of the hood. The overhead camera failed during the Operational Acceptance Test (OAT). This camera also had a more limited view than was intended by the project team. Automatic cleaning using an air blowing system was provided to remotely clean the viewport windows although problems with air cleaning had been experienced in other ISV operations and a mechanical wiper system had been recommended in an ISV project document. When this system did not perform to expectations, its use was discontinued. Routine manual cleaning was instituted; however, the viewport window of the functional camera repeatedly became dirty shortly after being cleaned. The significant effort required to keep the viewport clean became tedious and project personnel decided to discontinue the effort. Minimal video monitoring was functional on the hood at the time of the event.

Problems were experienced during ISV operation with leakage in the water spray suppression system. As a result, the system was isolated and required local, manual actuation.

Thermocouples were installed prior to the melt to assist in measuring the depth and shape of the melt. The only other alternative to measuring the melt size and depth was by physically probing with rods. Most of the thermocouples were type K, which are destroyed if contacted by molten material. Failure of the thermocouples after heating above 1200°C was interpreted to indicate that the melt had reached their depth or lateral position. Problems occurred during the OAT with all but two of the ~38 thermocouples due to spurious data thought to have been caused by bundling the thermocouple wires. Following the OAT, four additional thermocouples were emplaced, two on each of two sides of the melt.

The emergency off-gas blower was originally intended to activate automatically in response to hood pressurization, but the computer batch logic that activated this system interfered with power application to the melt. This blower was reconfigured to require manual activation in the event of loss of the primary off-gas system. It was not designed to handle the volume of steam/gases from a large MEE and, since the primary off-gas system remained in operation at the time of the event, was not activated.

Section 10.1.5.3 of the "Safe Operating Procedure for the ISV Large-Scale System" states that "if a pressurization occurs for greater than 5 seconds, DPIC-101 will activate the batch logic for low hood vacuum. The operator must verify the batch logic sequence actions have shut down the power to the electrodes . . ." Project personnel stated that, due to operational problems with the batch logic associated with DPIC-101, the shutdown had been modified from automatic to manual.

During ISV operations, the "safety zone" discussed previously in Sect.2.6 of this report was, in practice, an electrical protection zone (nonconducting boots and gloves required for entry) and a radioactive contamination control zone. Because of electrical hazards, personnel are never allowed to be on the hood while power is applied to the electrodes. A change request form was completed on April 2, 1996, which stated that personnel were prohibited against entry anywhere inside the electrical safety zone when the electrodes are energized. This statement was globally applied to all tasks. However, following additional evaluation of electrical hazards, entry was allowed into the safety zone, which surrounds the hood, shortly after the change request form was completed. Personnel inside the safety zone near the hood could be exposed to the thermal and pressure effects of an MEE.

The project team did not perform a systematic, written evaluation of the OAT before proceeding with the full-scale melt in Pit 1.

The "ER Facility Conduct of Operations Applicability Matrix for WAG 7 ISV, Rev. 1," approved by Robert C. Sleeman on August 23, 1995, addresses compliance with requirements from DOE Order 5480.19: (8-C.5), Equipment Deficiency Identification and Documentation, (8-C.9), Temporary Modification Control, and (16-C.3), Procedure Changes and Revisions. In addition, the *Health and Safety Plan for the Environmental Restoration Program at Oak Ridge National Laboratory*, ORNL/ER-226, provides a change control process to ensure that all variances and changes to the site-specific HASP are controlled. However, Chap. 20 of the site-specific HASP for the ISV project lists all of the types of conditions that would require a revision to the HASP. Changes to protective or mitigative equipment are not one of the conditions mentioned in Chap. 20 as requiring a HASP revision. Approved changes that were made to the record copy of the HASP included the site map and updates of key personnel. The record copy did not indicate variances to the status and configuration of ISV equipment such as vent pipe location below the melt, installation of all vent socks, water spray suppression system capacity and functionality, video monitoring and recording, and in situ heating of the pit. In addition, the "Standard Operating Procedure for the Large-Scale System" was not revised to indicate changes to the control logic for the emergency off-gas hood blower and electrode power shutdown. No evidence was provided that an evaluation of these variances was performed comparable to the level of review and approval of the original project documents before decisions were made to proceed with ISV operations.

2.10 PERSONNEL OCCUPANCY

Interviews were conducted with the project team leader to determine the amount of the time personnel were required to be on or around the platform in order to operate the equipment. He estimated that personnel were on or around the hood performing activities that totaled ~ 9.4 person-hours per 24-hour period. This estimate includes the time personnel were in the safety zone when power was applied to the electrodes and when the electrodes were de-energized. Maintenance activities were not included in the estimate, nor were unique operations that occurred during this melt, which would probably not be expected to occur in the future. The person-hour/day total reflects that period of time per day that it would be possible to expose personnel to hazardous energy, without regard to maintenance or unforeseeable requirements.

The project team leader stated that the probability of an MEE occurrence decreases with time after power is shut off to the melt and that delaying entrance to the safety zone may reduce the potential for exposing personnel to hazards from an MEE. There are currently no clear technical bases for establishing an appropriate wait time.

Stairs are provided on the north and south sides of the off-gas hood platform. These stairs run from ground level to the platform surface, and provide adequate entry and exit from the platform during normal operation. However, exit from or entry to the platform using these stairs during an MEE would expose personnel to the hot gases.

2.11 EMERGENCY RESPONSE AND AMELIORATION

Emergency communication systems as described in the HASP include an air horn, voice communication, phones, and a public address system. The air horn is used as an emergency evacuation alarm. No air horn was available in the operations trailer at the time of the event. Since the site is relatively small, voice communication is normally used to communicate with workers outside the trailers or when working on the hood. Site personnel stated that voice communications may be ineffective in some areas because of equipment noise. Portable phones are occasionally provided and hard wired phones are available in the control trailer to communicate with the laboratory shift supervisor. The public address system provides communications between the operations trailer and the off-gas scrubber trailer.

The emergency response procedures, training, and drills did not address a large MEE.

The ORNL Emergency Preparedness Coordinator stated that the ORNL emergency squad had been briefed on the normal operating hazards such as electrical hazards and the location of the power cut-off switch. He stated that he had not received instructions related to the use of water on the molten radioactive glass. The project team leader stated that after he arrived during the event, he advised the fire department not to use water on the fires because the amount of combustibles was limited and he was unsure that the use of water on the molten glass would not contribute to environmental releases of radioactivity. He manually isolated electrical power to the ISV site from the main transformer and shut off the backup diesel generator after it started.

3. ANALYSIS

3.1 SUMMARY

The investigation team determined that the probability of recurrence of a similar or greater event may not be reduced sufficiently by current engineering controls and therefore must be addressed in terms of protecting people from an MEE, particularly near the end of melts. Additionally, there are currently no consistent warning indications that can be relied on to provide an adequate level of personnel protection.

3.2 MANAGEMENT OVERSIGHT AND RISK TREE ANALYSIS

Management Oversight and Risk Tree analysis results indicated that the technical information (experience from previous ISV operations) showed that an MEE was statistically possible. While the project team and readiness review personnel evaluated the potential for an MEE and the controls to prevent or to mitigate such an event, their understanding of the MEE phenomena was not sufficient to eliminate an MEE from consideration as a DBE and to be able to rely solely on prevention. As a consequence, less than adequate consideration was given to protection of personnel working on or around the hood if such an event did occur. The investigation team concluded that this was most likely the result of a less than adequate understanding of the causes of previous melt expulsions and/or of the characteristics of Pit 1, believing that engineered controls would reduce the probability of occurrence to negligible and focusing on control of radiological and electrical hazards.

The investigation team also concluded that the constructability and operability of preventive and mitigative systems as described in the HASP were not properly evaluated. Installation of the vent pipe system below the very bottom of the melt was not accomplished as stated in the HASP. The water spray suppression system could not mitigate a large MEE even though the HASP seems to indicate that it can, based on the reference to nuclear reactor containment spray systems that are much larger in terms of capacity and delivery rates. However, no one interviewed believed that the spray system, as designed, could actually mitigate an MEE.

The practice of maintaining equipment status and configuration was determined to be less than adequate based on comparing actual equipment status and configuration to that described in the HASP. A possible cause is that equipment and systems necessary to ensure safe operations were never clearly defined as safety systems by the project team. However, the investigation team must note that there is no assurance that the full maintenance of this equipment status and configuration would have prevented the MEE.

Since a large MEE was not considered as a probable event, emergency plans did not adequately address the measures to protect personnel on or around the hood, ensure safe egress from these areas, or to plan responses specific for an MEE by the fire department. The decision to cut off all electric power to the site in case of fire would prevent the off-gas system from maintaining a controlled, filtered release.

3.3 BARRIER ANALYSIS

Barrier analysis examined the energy flows based on the assumption that a bubble formed and rose through the melt to expel molten material and steam. The purpose was to identify possible barriers to personnel injury.

Flammable material was prohibited in the safety zone; however, the presence of combustible materials around the hood should be minimized. Evaluation for safe egress from the hood such as stair location and configuration should be conducted. The possibility of directing the hazardous energy and gases in a safe direction should be considered.

Because there are no consistently reliable warning indicators that can ensure personnel are isolated from MEE hazards, time in hazardous areas should be minimized (separation in time and space), especially near the end of melts when the probability of an MEE has historically increased. Barriers on personnel such as thermally-resistant clothing, should be evaluated for those occasions that personnel must be in the hazard area.

Variances to operational equipment and safety documents should be documented through the change control process to ensure that they receive appropriate review and approval prior to implementation.

3.4 KEY DECISION POINTS

Several key decision points during the ISV project planning and execution were identified that may have contributed to the event or to the failure to adequately plan for the event:

- The safety analysis (in the HASP) was prepared by project personnel and not by an independent safety analysis professional.
- During the preparation, review, and approval of the safety analysis in the HASP, an MEE was not judged to be likely enough to consider a DBE.
- The HASP safety analysis was judged to be adequate to serve as the Auditable Safety Analysis, and a separate safety analysis did not need to be conducted.
- During the readiness review process, and MEE was not judged to be likely enough to consider a DBE.
- Modifications of the operability and controls for equipment described in the HASP as preventive or mitigative measures for an MEE did not receive the same level of review initially given the HASP.
- Corrective actions from past events focused on engineered controls (even though the phenomena is not well understood) and did not address personnel protection in mitigating hazards.
- No systematic, written documentation of the assessment of the OAT was done.

4. CONCLUSIONS

4.1 SUMMARY

The investigation team concluded that the probability of recurrence of a similar or greater DBE may not be reduced sufficiently by engineering controls to continue to support the assumption that the probability is remote. Therefore, additional measures should be taken to ensure personnel working at the site are protected from the potentially hazardous energy sources released during such an event. Also, improved change control is required to ensure variances to safety systems receive appropriate review and approval and appropriate documentation in project documents.

4.2 FINDINGS

A large MEE was not considered as a DBE and personnel protection from MEE hazards was not included in the HASP.

Change control was not adequate to ensure that changes to the status and configuration of equipment described in project documents such as the HASP received evaluation comparable to the original review and approval of those project documents. The investigation team must note that there is no guarantee that the full implementation of the equipment and measures described in the HASP would have prevented the MEE.

4.3 PROBABLE CAUSES

The probable reasons for not considering an MEE as a DBE include the following:

- less than adequate understanding of the causes of previous melt expulsions and/or the characteristics of Pit 1.
- lack of aggressive consideration of the likelihood of an MEE by the safety analysis (HASP) and readiness review processes,
- lack of recognition of "safety systems" and failure to ensure variances in the construction and/or maintenance of these systems is properly evaluated in the change control process.
- focus on radiological and electrical hazards instead of hazards of pressure and temperature.
- less than adequate rigor in the conduct of operations due to the project hazard classification as non-nuclear.

4.4 RECOMMENDATIONS

Before ISV operations at ORNL are resumed, the investigation team recommends that the following be conducted:

- Consider the largest credible MEE as a full DBE including personnel protection, equipment design, and emergency planning. Review again the lessons learned from the three previous MEEs.

- Identify important safety and process control systems and administrative controls and ensure that variances to these systems and controls go through the change control process for appropriate review and approval.

- Evaluate the feasibility of designing the hood to vent/filter gas releases from a large MEE in order to protect personnel and retain the sealing around the edge for confinement of gas and melt. Give priority to on-site personnel safety and ensure environmental considerations, including air-permitting and ambient air monitoring.

- Reevaluate the safety requirements for personnel protection in the event of an MEE to include consideration of minimizing personnel working time on or around the hood, improvement of site communications, adequacy of the emergency evacuation alarm, thermally shielded egress from the hood, adequacy of emergency preparedness plans, and minimizing combustible items around the hood. Consider the location and protection of the operations and process trailers relative to the hood for various future melt settings.

- Improve data collection (e.g., video monitoring, frequency of data logging, and ease of data downloading for post-event analysis) to better understand MEEs, and identify potential MEE precursors and indications if possible.

Appendix A

LETTER OF APPOINTMENT

06/1?/96 WED 13:59 FAX 615 576 6074 ERD D-5 B'WAY OAK RIDGE 002

KT

Department of Energy

Oak Ridge Operations Office
P.O. Box 2001
Oak Ridge, Tennessee 37831—

April 25, 1996

Ms. Fran DeLozier, Director
Environmental Restoration Program
Lockheed Martin Energy Systems, Inc.
Post Office Box 2003
Oak Ridge, Tennessee 37831

Dear Ms. DeLozier:

INVESTIGATION OF IN SITU VITRIFICATION (ISV) MELT INCIDENT

As a result of the ISV melt incident, it is requested that a separate independent investigation be performed in addition to the Occurrence Investigation and Analysis Report currently initiated by Brian Spalding and the project team under DOE M 232.1-1. As the Occurrence Investigation Report will focus on root causes of the incident, the scope of the independent investigation will focus on Environment, Safety and Health concerns such as the adequacy of the ISV safety systems, operational control restrictions, emergency response planning/execution, and readiness review.

It is requested that three to five Lockheed Martin Energy Systems, Inc., employees be appointed to serve on the independent investigation team. Tim Wilson, Office of Assistant Manager for Environment, Safety, and Quality has been appointed to participate in the investigation on the Environmental Restoration Division behalf. Please provide to me the names of the employees that will be serving on the investigation team by April 26, 1996.

This independent investigation should be finalized 45 days from the date of the incident to coincide with the initial submittal of the Occurrence Investigation Report to the Department of Energy Headquarters. The two teams will share information and this approach will allow optimum use of personnel and enable a better understanding of the incident and improvements to control measures.

If you need assistance or any additional information, please contact John Sweeney at 576-5904.

Sincerely,

for Robert C. Sleeman, Director
Environmental Restoration Division

see ccs on page 2

cc:
R. Nelson, EW-90, ORO
Bob Poe, SE-30, ORO
Ron Hultgren, ER-11, ORO
E. Cumesty, ER-12, ORO
J. Sweeney, EW-911, ORO
K. Leifheit, SE-331, ORO
B. Holder, EH-24, MS-9114
T. Allen, EW-96, ORO

Appendix B

OCCURRENCE REPORT

ORO--LMES-X10ENVRES-1996-0006

OCCURRENCE REPORT

X10ENVRES - X-10 Environmental Restoration Program

(Name Of Facility)

Environmental Restoration Operations

(Facility Function)

Oak Ridge National Laboratory

(Name of Laboratory Site or Organization)

Name: J H HOOYMAN
Title: FACILITY MGR. DESIG. Telephone No.: (423)576-6489

(Facility Manager/Designee)

Name: B P SPALDING
Title: LEAD SCIENTIST Telephone No. (423)574-7265

(ORIGINATOR)

1. OCCURRENCE REPORT NUMBER: ORO--LMES-X10ENVRES-1996-0006
   Action Item Reference ID: I0030284 -
   Source ID Number:

2. REPORT TYPE AND DATE: Date Time

   [X] Notification Report 04/22/1996 15:42
   [ ] Initial Update
   [ ] Latest Update
   [ ] Final Report

3. OCCURRENCE CATEGORY:

   [ ] Emergency
   [X] Unusual
   [ ] Off-Normal
   [ ] Non-Routine
   [ ] Void

4. NUMBER OF OCCURRENCES: 01 ORIG. OR:

5. DIVISION OR PROJECT: ISV Project

6. SECRETARIAL OFFICE: EM - Environmental Restoration and Waste Management
7. SYSTEM, BLDG., OR EQUIPMENT:
   OTHER

8. UCNI? No

9. PLANT AREA: WAG 7

10. DATE AND TIME DISCOVERED:
    04/21/1996 18:08

11. DATE AND TIME CATEGORIZED:
    04/21/1996 19:14

ORO--LMES-X10ENVRES-1996-0006

Notification Report
Page 2 of 5

OCCURRENCE REPORT

12. DOE NOTIFICATION:
04/21/1996 22:32 T . TANNER / DOE-HQ

13. OTHER NOTIFICATIONS:
04/21/1996 18:20 M W WISE / DOE-ORO
04/21/1996 19:14 L . RICHLEN / TEMA
04/21/1996 19:30 R O HULTGREN / DOE-ORNL

14. SUBJECT OR TITLE OF OCCURRENCE:

Fire at In Situ Vitrification (ISV) Site

15. NATURE OF OCCURRENCE:

1B Facility Condition - Fires/Explosions

1H Facility Condition - Operations

10C Potential Concerns/Issues

16. DESCRIPTION OF OCCURRENCE:

During normal in situ vitrification (ISV) operations at an ORNL radioactively-contaminated soil waste disposal site, a large thermal and pressure transient occurrence within the off-gas collection hood. This resulted in a fire of several combustible components (wire insulation, rubber tubing, etc.) on the hood structure.

Emergency responders were informed and monitored small smoldering fires. No personnel were injured or contaminated as a result of the incident. No detectable airborne contamination has been observed around the site perimeter. Numerous small pieces of contaminated glass have been found on the ground surfaces. The process has been shut down until further area radiological surveys can be completed and potential equipment damage assessed.

17. OPERATING CONDITIONS OF FACILITY AT TIME OF OCCURRENCE:

ISV operations were proceding normally at about 2 MW power to the melt for several days prior to the occurrence.

18. ACTIVITY CATEGORY:

Normal Operations

OCCURRENCE REPORT

- IMMEDIATE ACTIONS TAKEN AND RESULTS:
  Press Release Anticipated: YES

  The fire was monitored but due to high heat of the molten glass, no fire fighting actions were taken. The small amount of combustible materials on the hood self-extinguished within an hour of the initial fire. Radiation surveys of site personnel and equipment have not indicated any contamination.

---

20. DIRECT CAUSE:

21. CONTRIBUTING CAUSE(S):

22. ROOT CAUSE:

---

23. DESCRIPTION OF CAUSE:

---

24. EVALUATION: (by Facility Manager/Designee) COST EVALUATION:

    The ISV operation experienced a large "burp" of hot-gas (steam) which caused pressurization and high temperature to the containing off-gas hood. The process cannot be restarted until the cause of this unexpected occurrence is identified.

---

25. IS FURTHER EVALUATION REQUIRED: Yes [X] No [ ]
    IF YES, BEFORE FURTHER OPERATION: Yes [X] No [ ]
    IF YES, BY WHOM?BP SPALDING
    BY WHEN? 06/05/1996

---

26. CORRECTIVE ACTIONS:

---

27. IMPACT ON ENVIRONMENT, SAFETY, AND HEALTH:

---

28. PROGRAMMATIC IMPACT:

---

29. IMPACT UPON CODES AND STANDARDS:

---

30. LESSONS LEARNED:

---

31. SIMILAR OCCURRENCE REPORT NUMBERS:

OCCURRENCE REPORT

. . USER FIELD #1:
Energy Systems Action Management Systems Reference ID I0030284

33. USER FIELD #2:

34. DOE FACILITY REPRESENTATIVE INPUT:

Entered by: ______________________ Date: __________

OCCURRENCE REPORT

SIGNATURES:

____ Date:__________
Facility Manager (Name, Position)

____ Date:__________
DOE Facility Representative (Name, Position)

____ Date:__________
DOE Program Manager (Name, Position)

Appendix C

INTERVIEWED PERSONNEL AND REVIEWED EVIDENCE DURING INVESTIGATION

PERSONNEL AND EVIDENCE

The following personnel were interviewed by the investigation team:

B. P. Spalding, LMER
J. S. Tixier, PNL
M. T. Naney, LMER
L. S. Hawk, LMER
M. A. Bogle, LMER
W. K. Crowley, LMES
R. D. Nipper, Jr, LMES
C. A. Taylor, LMES
B. E. Copeland, LMER
C. Clark, Jr., LMES
P. A. Schrandt, LMER
J. E. Irwin, LMER
M. L. Sizemore, DOE-ORO
D. E. Paul, DOE-ORO

The following is a listing of the evidence that was reviewed by the investigation team:

Site Safety Health Plan (Phase III) for the Treatability Study for In Situ Vitrification at Seepage Pit 1 in Waste Area Grouping 7, ORNL/ER-314, June 1995.

Treatability Study Work Plan for In Situ Vitrification of Seepage Pit 1 in Waste Area Grouping 7 at Oak Ridge National Laboratory, Oak Ridge, Tennessee. DOE/OR/01-1158. July 1994.

Approval of the Treatability Study Work Plan (DOE/OR/01-1158&D2) for In-Situ Vitrification of Seepage Pit 1 in Waste Area Grouping 7, at the Oak Ridge National Laboratory, Oak Ridge, Tennessee. E. M. Carreras to W. M. Lingle, January 7, 1994.

Approval of the Treatability Study Work Plan In Situ Vitrification of Seepage Pit 1, Waste Area Grouping 7, Oak Ridge National Laboratory, DOE/OR/01-1158&D1. R. D. McCoy to W. M. Lingle. October 12, 1993.

Readiness Review Plan for the In Situ Vitrification Demonstration of Seepage Pit 1 in Waste Area Grouping 7. ORNL/ER-294. May 1995.

ORNL Pit 1 In Situ Vitrification Treatability Study Test Plan. Revision 0.March 1996.

Site Characterization Activities Summary for ORNL Seepage Pit 1 Prior to Its Use for In Situ Vitrification. September 1994 (draft).

Design and Fabrication Procurement Specification for an In Situ Vitrification Off-Gas Hood System. P.O. No. 293422. June 30, 1994.

Preliminary Safety Assessment LLW Pit 1, West of SWSA 4 Chemical Waste Area Access Road. PSA/7805-WMRAD/80. April 1995.

ER Facility Conduct of Operations Applicability Matrix for WAG 7 ISV, Rev. 1. June 28, 1995. Approved by Sleeman letter of August 23, 1995.

Quality Assurance Project Plan for Treatability Study of In Situ Vitrification of Seepage Pit 1 ORNL Waste Area Grouping 7, Phase III ISV melting Operations and Post Test Characterization of Pit 1, ORNL/ER-307. July 1995.

Severe Weather Plan In-Situ Vitrification Demonstration Site. Revision 0, September 11, 1995.

Safe Operating Procedure for ISV Large-Scale System. Procedure No. 58, Rev. 9., Battelle Pacific Northwest Laboratory. June 1995.

Safe Operating Procedure for the In Situ Vitrification Hood Off-Gas Collection and Filtration System. ISV-TS-P95. Revision 0.1. March 6, 1996.

Water Spray Suppression System. ISV-TS-H2O. March 18, 1996.

Site Safety and Health Briefing Outline. ISV-TS-P08. September 1995.

Training records.

ES&H Operator Aid.

List of Approved Change Requests for ISV Treatability Study at ORNL Pit 1

Excerpts from ISV Pit 1 operations log book

Selected evidence from FRT readiness review files

Statements from MEE eyewitnesses

Preliminary damage assessment of ISV Off-Gas Hood System, J.S. Tixier, 5/1/96

ISV Pressurization Incident—Final Report of the Investigation Committee, PNL, 11/18/91

Preliminary Investigation of the Potential for Transient Vapor Release Events During In Situ Vitrification Based on Thermal-Hydraulic Modeling, PNL, 7/92

Investigation Into the Causes and Application Significance of the Melt Displacement Event Occurring During Geosafe Operational Acceptance Test #2, Geosafe Corporation, 5/14/93

Personal communication of "Compilation of Data from the Large-Scale UTV Test" from Spalding

Appendix D

IN SITU VITRIFICATION TREATABILITY STUDY ORGANIZATION CHART

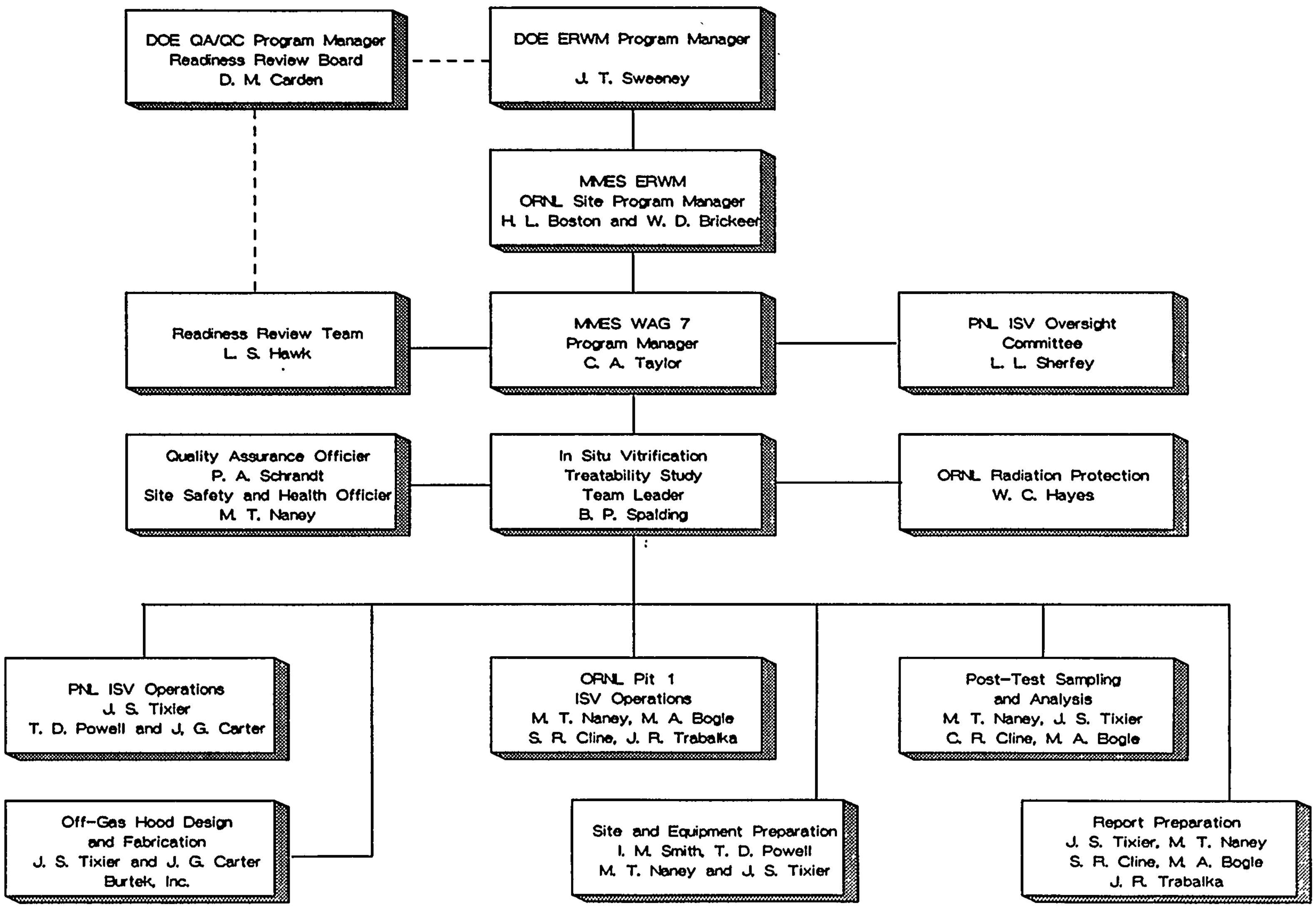
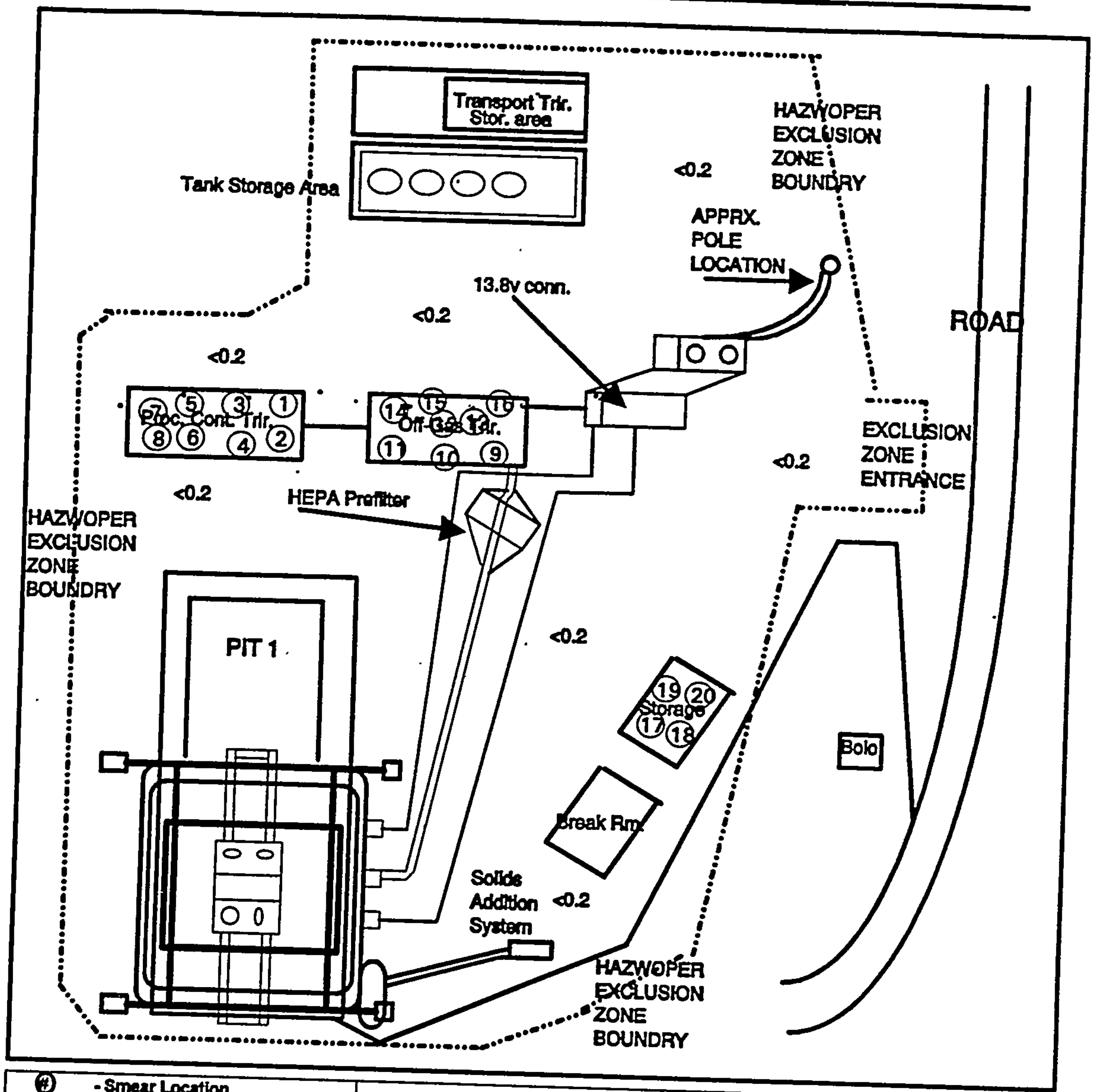


Fig. 5. In situ vitrification organization chart.

Appendix E

RADIOLOGICAL SURVEY DATA BEFORE AND AFTER EVENT

Survey Number: CAP-96-0205 | **CAP Field Office** | Date: 4/20/96 | Time: 21:00



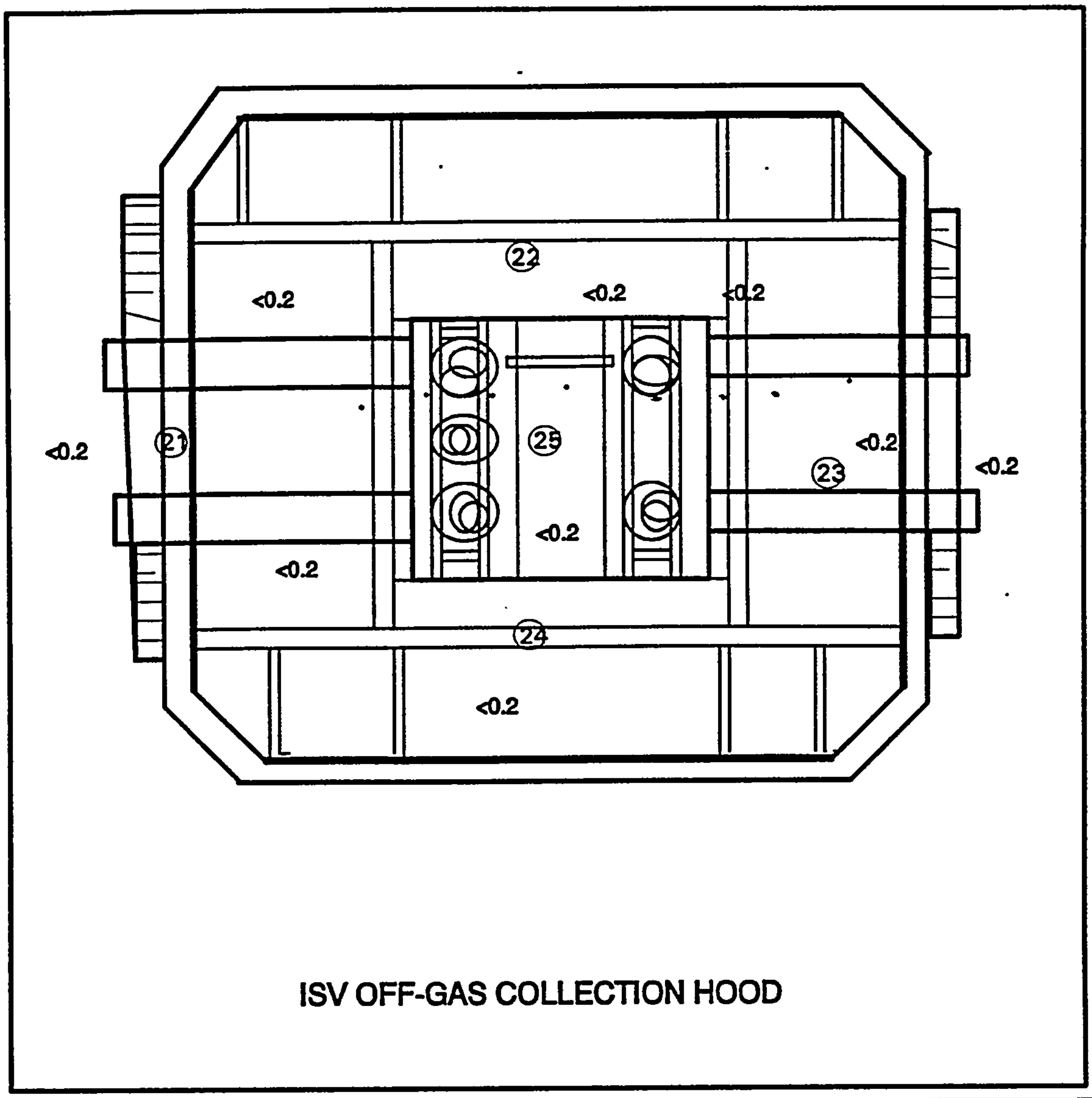
Symbol	Description	Boundary Designations	
(#)	- Smear Location	RA - Radiation Area	BA - Radiological Buffer Area
(#)—(#)	- Large Area Smear	HR - High Radiation Area	CA - Contamination Area
# (underlined)	- Contact Dose Rate	VR - Very High Radiation Area	HC - High Contamination Area
# (overlined)	- 30 cm Dose Rate	AR - Airborne Radioactivity Area	FC - Fixed Contamination Area
#	- General Area Dose Rate	RM - Radioactive Materials Area	SC - Soil Contamination Area
[SOP]	- Step-off Pad	UM - Underground Radioactive Materials Area	
AS	- Air Sample Location		

Default units are in mR/hr and are for open window beta/gamma readings. Letter suffixes with the number indicate specific radiations: B - Beta (mRad/hr), G - Gamma (mR/hr), N - Neutron (mRem/hr). Boundary designations are looking from the designations into the zoned area.

Page 2

Fig. 6. Oak Ridge National Laboratory radiological survey data (before the event).

Survey Number: CAP-96-0205 | **CAP Field Office** | Date: 4/20/96 | Time: 21:00



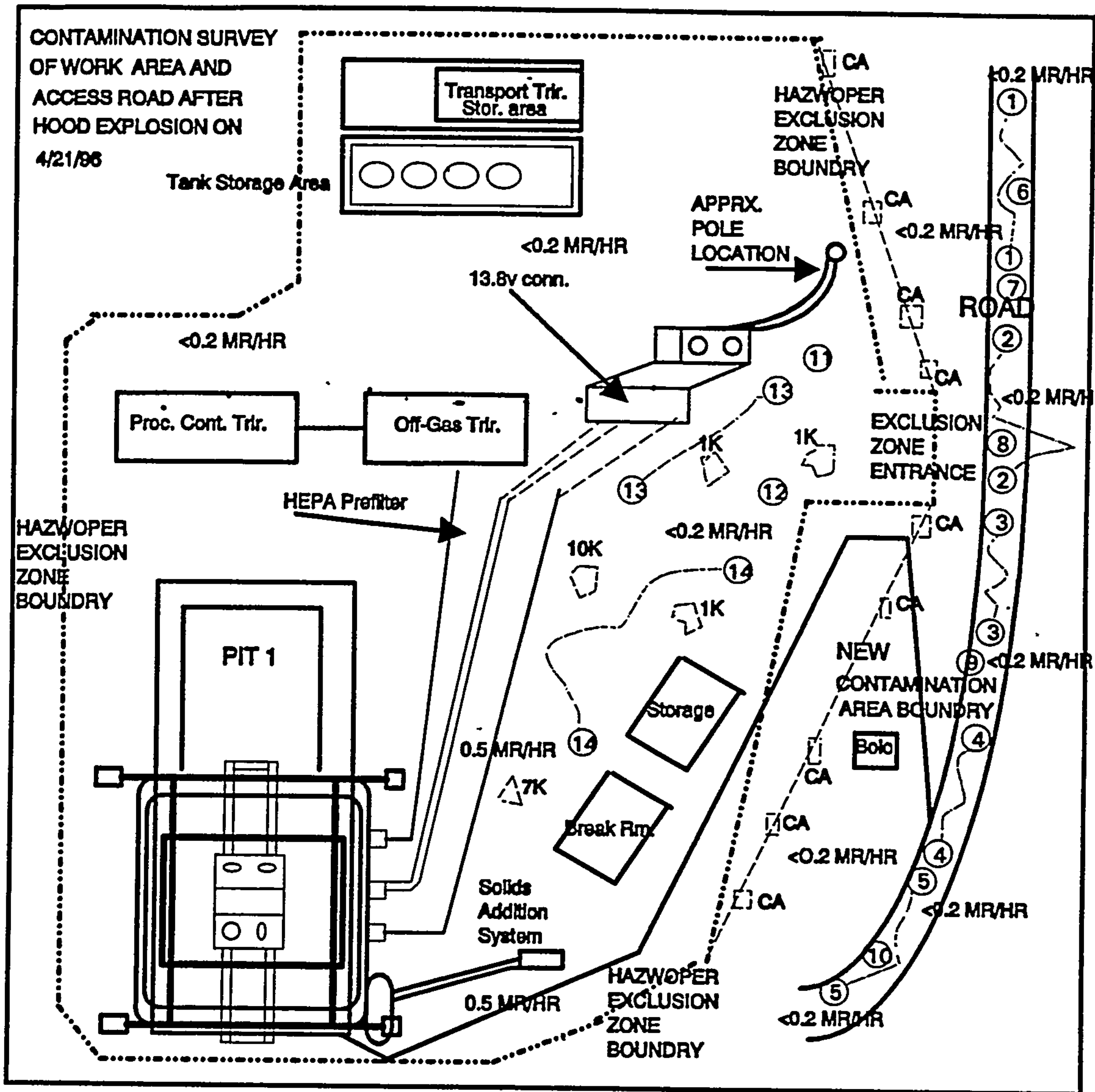
		Boundary Designations	
(#)	- Smear Location		
(#)—(#)	- Large Area Smear	RA - Radiation Area	BA - Radiological Buffer Area
# (underlined)	- Contact Dose Rate	HR - High Radiation Area	CA - Contamination Area
# (overlined)	- 30 cm Dose Rate	VR - Very High Radiation Area	HC - High Contamination Area
#	- General Area Dose Rate	AR - Airborne Radioactivity Area	FC - Fixed Contamination Area
SOP	- Step-off Pad	RM - Radioactive Materials Area	SC - Soil Contamination Area
AS	- Air Sample Location	UM - Underground Radioactive Materials Area	

Default units are in mR/hr and are for open window beta/gamma readings. Letter suffixes with the number indicate specific radiations: B - Beta (mRad/hr), G - Gamma (mR/hr), N - Neutron (mRem/hr). Boundary designations are looking from the designations into the zoned area.

Page 3

Fig. 7. Oak Ridge National Laboratory radiological survey data (before the event).

Survey Number: CAP-96-0208 | **CAP Field Office** | Date: 4/22/96 | Time: 18:00



		Boundary Designations	
(#)	- Smear Location		
(#)—(#)	- Large Area Smear	RA - Radiation Area	BA - Radiological Buffer Area
#	- Contact Dose Rate	HR - High Radiation Area	CA - Contamination Area
#	- 30 cm Dose Rate	VR - Very High Radiation Area	HC - High Contamination Area
#	- General Area Dose Rate	AR - Airborne Radioactivity Area	FC - Fixed Contamination Area
SOP	- Step-off Pad	RM - Radioactive Materials Area	SC - Soil Contamination Area
AS	- Air Sample Location	UM - Underground Radioactive Materials Area	

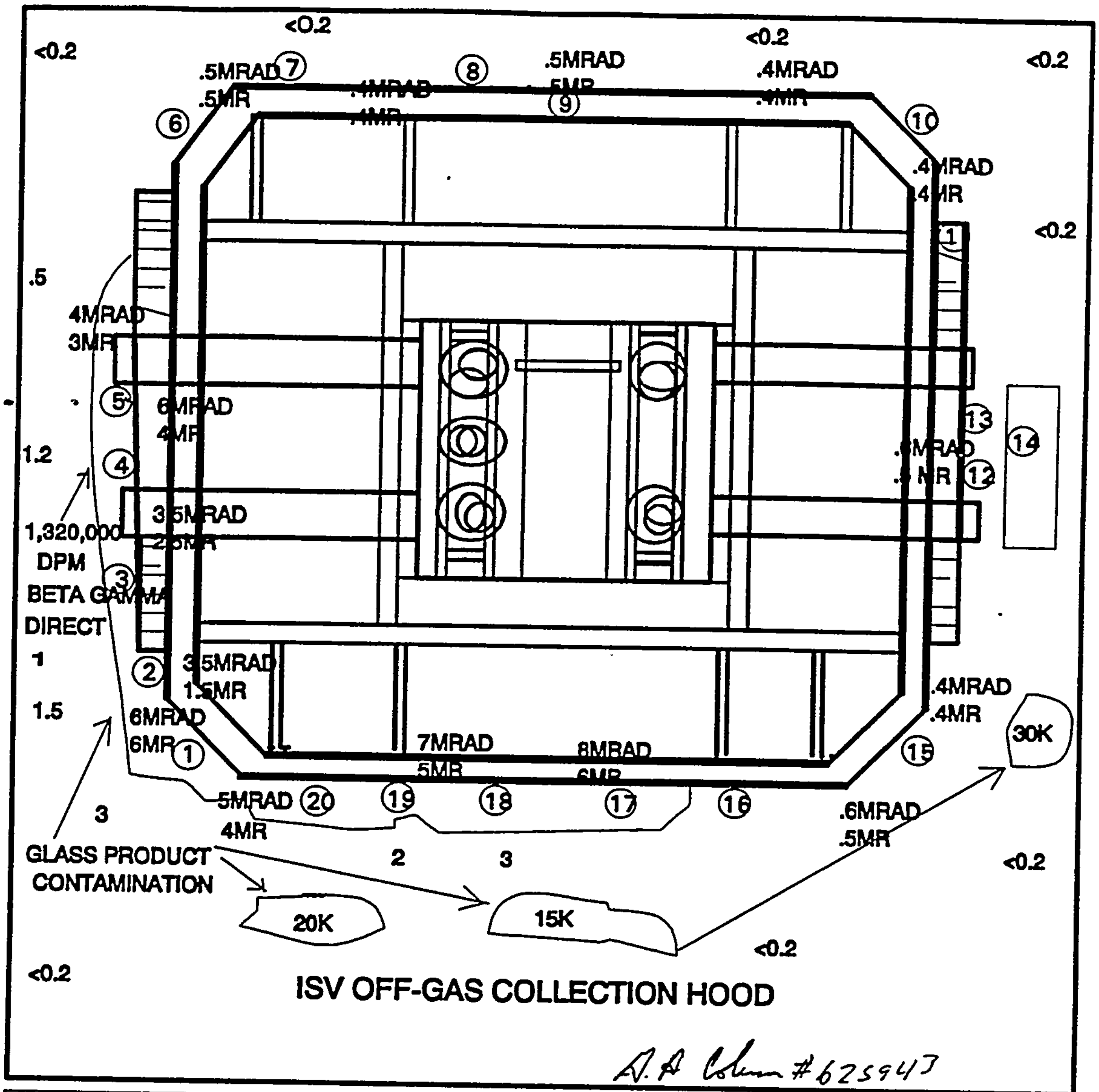
Default units are in mR/hr and are for open window beta/gamma readings. Letter suffixes with the number indicate specific radiations: B - Beta (mRad/hr), G - Gamma (mR/hr), N - Neutron (mRem/hr). Boundary designations are looking from the designations into the zoned area.

D. A. Colun #625943

Page 2

Fig. 8. Oak Ridge National Laboratory radiological survey data (after the event).

Survey Number: CAP-96-0210 | CAP Field Office | Date: 4/23/96 | Time: 6:15



		Boundary Designations	
(#)	- Smear Location		
(#)—(#)	- Large Area Smear	RA - Radiation Area	BA - Radiological Buffer Area
# (underlined)	- Contact Dose Rate	HR - High Radiation Area	CA - Contamination Area
#	- 30 cm Dose Rate	VR - Very High Radiation Area	HC - High Contamination Area
#	- General Area Dose Rate	AR - Airborne Radioactivity Area	FC - Fixed Contamination Area
SOP	- Step-off Pad	RM - Radioactive Materials Area	SC - Soil Contamination Area
AS	- Air Sample Location	UM - Underground Radioactive Materials Area	

Default units are in mR/hr and are for open window beta/gamma readings. Letter suffixes with the number indicate specific radiations: B - Beta (mRad/hr), G - Gamma (mR/hr), N - Neutron (mRem/hr). Boundary designations are looking from the designations into the zoned area.

Page 2

Fig. 9. Oak Ridge National Laboratory radiological survey data (after the event).

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