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THE FEBRUARY 21, 1993 TORNADOES OF EAST TENNESSEE

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Oak Ridge Y-12 Plant
Oak Ridge, Tennessee 37831
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A series of tornadoes struck the east Tennessee area on Sunday afternoon, February 21, 1993 around Knoxville, Lenoir City, and Oak Ridge causing millions of dollars worth of damage to both homes and businesses in the area, killing one, injuring a number of persons, and leaving a large area without power for many hours or even days due to damage to the local TVA transmission line network. One tornado touched down in the Department of Energy Oak Ridge Reservation near the Oak Ridge Y-12 Plant*, continued through the Union Valley business district located just east of the plant, through the adjacent University of Tennessee Arboretum and then continued into the communities of Claxton and Powell. The path length of the tornado was approximately 13 miles. Damage to the Y-12 Plant was minimal, but the Union Valley business district was seriously damaged, including the Fusion Energy Design Center (FEDC) which houses a number of DOE related projects. The preliminary cost estimate of the damage to DOE facilities (both at Y-12 and at the FEDC) was around $520,000. This paper describes the local meteorological data, the tornado that struck near the Y-12 plant, the resulting damage both to the DOE facilities and to the surrounding communities, the plant emergency response and recovery activities, and the current hazard analyses being undertaken at the plant.

INTRODUCTION

The U.S. Department of Energy's (DOE) Oak Ridge Reservation (ORR) is located within the corporate limits of the city of Oak Ridge in eastern Tennessee (Figure 1). On Sunday afternoon, February 21, 1993 severe thunderstorm conditions produced a group of tornadoes in the Tennessee River Valley. One of these tornadoes formed near and passed through the northeastern edge of the Oak Ridge Y-12 Plant. A number of nearby towns were struck by other tornadoes spawned from the same system.

At Y-12, the tornado caused damage to trees, signs, building exteriors and roofs, vehicles, power lines, and utility poles. A power outage affected a large portion of the plant facilities. Although damage to DOE-owned facilities was relatively light, the cost estimate for repairs was approximately one half million dollars. The path of the tornado was fairly narrow and about 13 miles long, striking the

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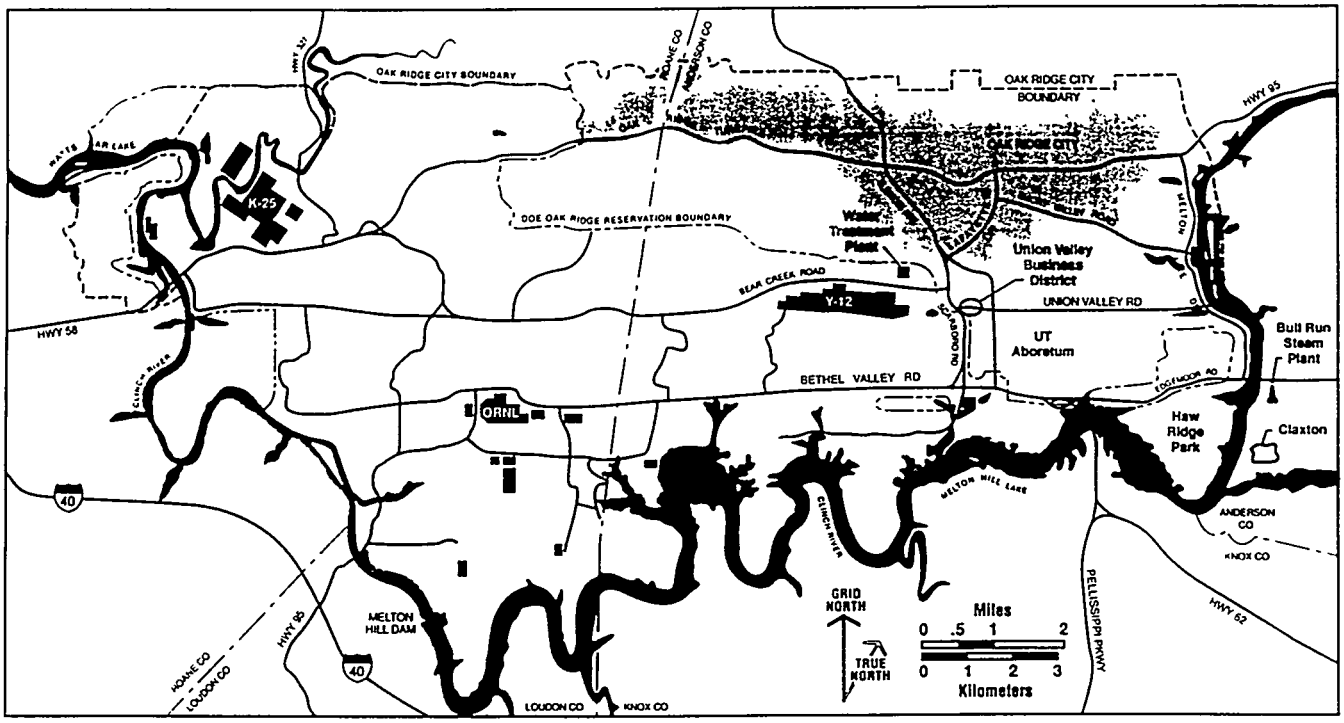

Figure 1. Oak Ridge Reservation Vicinity Map

adjacent Union Valley Industrial Park, University of Tennessee (UT) Arboretum, and the communities of Claxton and Powell. The tornado caused significant tree damage in the local area and resulted in varying damage to homes, trailers, and other structures along its entire path length. The wind speeds associated with this tornado are estimated to range from about 40 mph to a maximum around 130 mph, depending on the location along the path. Existing site emergency plans and procedures were followed. The Y-12 Emergency Operations Center (EOC) was activated, response personnel were mobilized on-site and others were called in. No injuries occurred, no hazardous materials were released, and it was determined that no hazardous material release potential existed as a result of the power outage. A special study [1] of the tornado event was conducted at the request of DOE and resulted in some positive observations of things that went well. In addition, it was learned that there was an opportunity for improvement and planned actions were identified. Lessons learned included the value of checklists, procedures, and training; preservation of evidence; traffic control; informing personnel of changing situations; recovery planning; protective actions; and damage prevention.

METEOROLOGICAL ASPECTS AND IMPACTS

SYNOPTIC SITUATION

A low-pressure system, with an attendant complex cold front, moved from the Mississippi River Valley into Tennessee on February 21, 1993. That frontal system strengthened during the day. The National Weather Service (NWS) issued a tornado watch for 57 counties in West and Middle Tennessee at 10:02 am. By midafternoon, a series of thunderstorms were spawned by a squall line preceding the frontal system. Cold air aloft, coupled with significant moist, low-level inflow from the Gulf of Mexico enhanced the system throughout the day. Radar observations from the NWS depicted widespread thunderstorm activity associated with the frontal system and the development of the midafternoon squall line. Showers and thunderstorms moved from West Tennessee into and through the middle of the state by early afternoon. A Special Weather Statement was issued at 1:12 pm by NWS, describing the conditions and emphasizing the danger of this system. Severe thunderstorm watches were issued by the NWS for Middle and East Tennessee at 2:26 pm. The storms grew progressively more intense

throughout the afternoon. Cloud tops of the thunderstorms of the approaching squall line grew to about 35,000 ft as measured by NWS radar in midafternoon. The storm system moved from west-southwest to east-northeast at about 35 to 40 mph. New cells continued to develop on the southern edge of the squall line as the system moved rapidly through Tennessee. East Tennessee is covered by NWS radar in Chattanooga and Nashville. As storm systems move through the Cumberland Mountains and into East Tennessee, radar coverage becomes less reliable because of ground clutter and radar beam angle, and speeds and cloud heights become more difficult to determine accurately.

The first tornado spawned by this system in Tennessee occurred in Crab Orchard in Cumberland County at about 3:07 pm, and the system moved generally eastward at approximately 45 mph. Other tornadoes were spawned as the system moved from the Cumberland Plateau into the Tennessee River Valley. Tornadoes touched down at Oak Ridge at 4:39 pm, Claxton at 4:45 pm, Powell at 5:05 pm, Lenoir City at 5:25 pm, and also at Friendsville, Englewood, and Tellico Plains. Lenoir City suffered extensive damage to a five square block residential area and portions of the adjacent business district; one person was killed, many others were injured, numerous buildings were severely damaged or destroyed, and widespread power outages occurred. The general locations of the tornadoes identified by the Tennessee Emergency Management Agency (TEMA) is shown in Figure 2.

As can be seen, the tornado paths were approximately parallel, and the storms generally moved in the direction of the squall line and frontal system. The tornadoes were accompanied by heavy rainfall and significant amounts of large hail. The squall line moved eastward, passing into the rough terrain of the Smoky Mountains. The storm system was weakened by the loss of diurnal heating as local sunset approached, and perhaps by disruption of the low-level moist inflow from the Gulf caused by the rougher terrain of the mountains.

MESOSCALE (The Oak Ridge-to-Powell Storm)

The thunderstorm that spawned the Oak Ridge

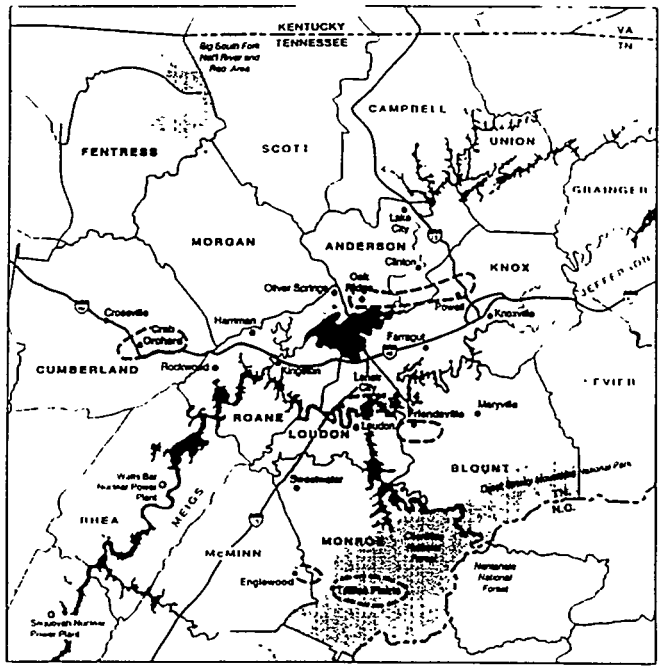

Figure 2. General Tornado Locations

to Powell tornado was detected on NWS radar, and had a cloud top of about 38,000 ft on the national radar depiction. The storm was part of the advancing squall line, and was traveling in an east-northeasterly direction at approximately 45 mph. Numerous cloud-to-ground lightning strikes were noted by the thunderstorm monitoring system at the K-25 Site, approximately 10 miles west of Y-12. At 4:39 pm a tornado formed on the south side of Pine Ridge just north of Y-12, and it initially touched down west of the Water Treatment Plant. It was at full strength by the time it reached the intersection of Bear Creek Road and Scarboro Road on the northeast corner of the plant. The tornado proceeded in an east-northeast direction through the Union Valley Industrial Park complex located less than half a mile from the plant, through the UT Arboretum, and through the northern section of Haw Ridge Park. It crossed the Clinch River and continued through the south side of Bull Run Ridge, where it went through the community of Claxton, immediately south of the Tennessee Valley Authority (TVA) Bull Run Steam Plant. The tornado crossed Melton Hill Lake causing some damage near the Mile 4 pumping station at Mehaffey Road, and it then continued in the same general direction for approximately another 6.5 miles, causing damage at a trailer park on the Clinton Highway and to and

businesses and houses in the Powell community in north Knoxville, after which the tornado dissipated. The total path length of the tornado was approximately 13 miles. The path width is estimated to be between 50 and 100 yards, varying along the length. The approximate path of this tornado is shown in Figure 3.

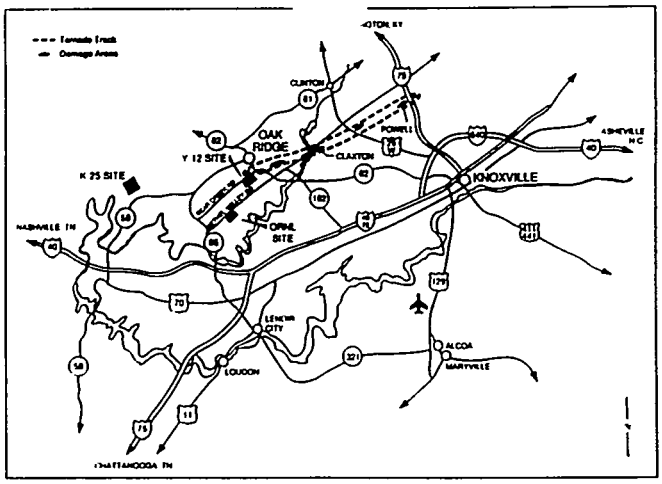

Figure 3. Oak Ridge-Powell Tornado Path

TORNADO DAMAGE

OAK RIDGE Y-12 PLANT

Damage from the tornado to the Y-12 Plant was relatively light since the path of the tornado passed [illegible] lant on the northeastern edge. Despite the [illegible] damage, the cost estimate for repairs and cleanup at Y-12 is on the order of $460,000. A brief listing of the tornado related damage follows:

General Site and Equipment: Shingles on the north wing of the Administration building (9704-2) were damaged and needed replacing. Guard Posts 2 and 6 (near the Biology entrance) received damage to canopies and miscellaneous electrical fixtures. The metal roof and guttering were damaged in Building 9959-2 (used for storage). Minor damage occurred to guttering, canopies, exhaust louvers, vent stacks, and service masts in Buildings 9219 (storage) and 9712 (Y-12 Plant Garage). The Graphic Arts/Photography Building (9766) had a door on the south side damaged and the northwest corner drip edge required reattaching. A roof leak occurred in A-wing of Building 9212 (a major Production facility). Miscellaneous damage to vacuum pumps, glass column adapters, power supplies, and alarm systems occurred in a number of Production and utility buildings. Power was lost to some operating equipment in Buildings 9215, 9204-4, and 9204-2E (all Production facilities).

Biology Complex Area: The built-up roof for the fan room on the laboratory portion of the Building 9207 (ORNL Biology/miscellaneous offices) was damaged. The south office annex built-up roof also was damaged. There was water damage in one room, and damage to the TV mast for the Hollander Auditorium. Insulation for the north supply fans was torn. In Building 9769 (ORNL Biology) the entry door and side glass seals were damaged, siding was partially stripped on the east and south exterior walls, and the argon trailer door and manifold was damaged. The control room roof of Building 9767-6 (Utilities) was damaged. Three translucent fiberglass panel wall sections, an interior drip shield, and the tarpaulin roof covering of Building 9621 (used for RCRA/TSCA storage) were destroyed, but the concrete frame of this small storage building was not damaged. In addition, miscellaneous damage to the Biology Complex Area included guttering, siding, and flashing. The cost for repairing the roofs in the Biology area was $67,000.

Monitoring and Surveillance Equipment: Numerous closed-circuit television camera systems and their tamper alarms were damaged along Bear Creek (plant north) and Mt. Vernon Roads (plant south). Two cameras at the Bear Creek Road Barrier were twisted and ripped from their mounts. The preliminary cost estimate for repairing these items was $32,000. In Building 9204-3 (ORNL Isotope Separation), 250 gallons of water spilled on the floor because of low air pressure from a loss of power. In Building 9219, sprinkler piping and an awning was damaged. An off-site warning system solar collector panel was damaged, as were pole-mounted speakers and part of the plant public address system. Some fire alarm system redundancy was lost. At the West Portal, a pole and one Perimeter Intrusion Detection and Alarm System (PIDAS) light were damaged.

Roads, Grounds, Signs, and Vehicles: About 25 traffic signs along Bear Creek Road were damaged

by the storm. These were replaced or repaired soon afterward. An Energy Systems information billboard and the main Y-12 Plant sign at the east end of Bear Creek Road were also blown over, knocking down some power and communications lines and blocking roads. The fallen trees were on the north side of Bear Creek Road and in the east end area of the plant, primarily outside of the security fence (Fig. 4).

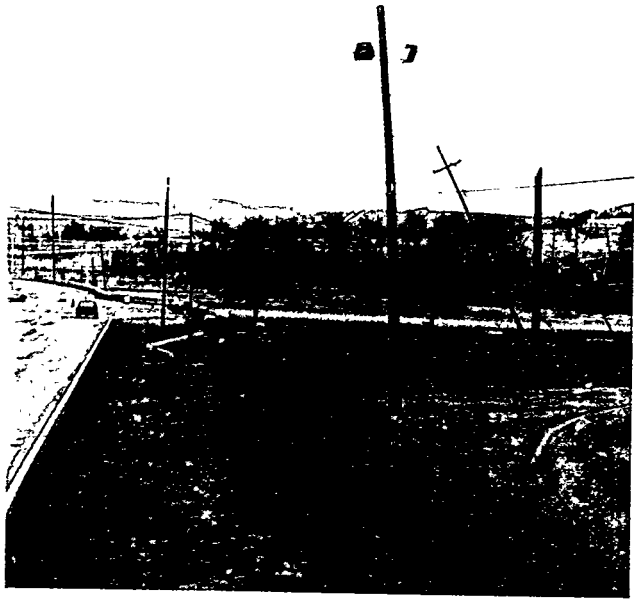

Figure 4. Damage to Trees, Poles, and Signs

Some trees were left in dangerous positions that required their removal. Near Lake Reality (far east end of the plant) a small trailer used as a staging area for environmental field activities was demolished. In the east end of the plant near the gasoline station, empty gasoline tanks were blown from a temporary, diked storage area, and a tanker and a large truck trailer were overturned (Fig. 5).

A number of vehicles and trailers were damaged when windows and windshields were shattered and other body damage occurred. The cleanup of the trees and the power lines further damaged the grounds on the east end of the plant which required additional cleanup and reseeding of the grounds.

High Voltage/Electrical Distribution Systems: The East River Line (Bear Creek and East Portals) was severely damaged. Six poles required replacement and/or straightening, and six spans of wire needed cleaning. The 161-kV lines on the south side of Bear Creek Road were knocked down. Portal 23 was temporarily out of service. Station 201

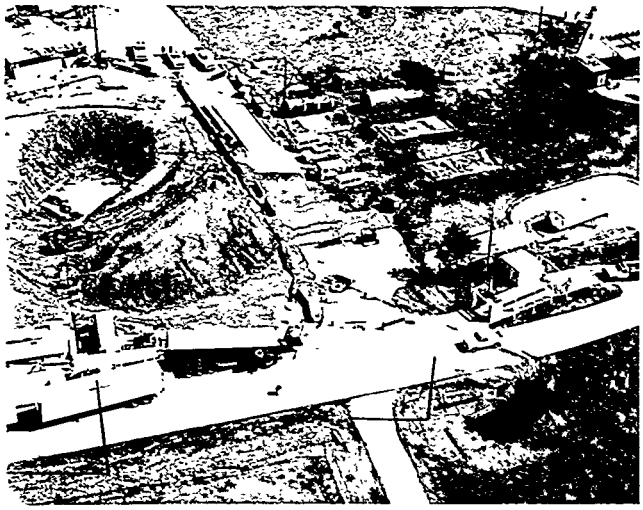

Figure 5. Empty Tanks Moved, Trailers Overturned

(Bear Creek and traffic lights) was out of service, and much of the electrical system and equipment (crossarms, lightning arresters, insulators, etc.) needed replacing and cleanup. The meteorological tower (330 ft) on the east end of the Y-12 Plant required replacement of six aircraft spherical warning markers. The cost of repairing the electrical and high-voltage systems was estimated at $62,600.

UNION VALLEY INDUSTRIAL PARK

The Union Valley Industrial Park, located near the east end of Y-12 between Scarboro Road and South Illinois Avenue is barely half a mile long. The storm destroyed two small buildings and damaged many of the remaining buildings, in addition to destroying trees, two TVA high-voltage transmission towers, and scattering debris throughout the area. The Dixie Electronics and 3S Safety Supply buildings, situated side by side about halfway along the road on the south side, were destroyed (Fig. 6).

These buildings were constructed primarily of unreinforced concrete block masonry walls tied to a light steel framework. The unreinforced masonry (URM) walls were knocked over and laid on their sides on the ground, with the ties ripped out of the masonry. A trailer located near the 3S Safety Supply building was damaged. Next to them is the Fusion

Engineering Design Center (FEDC), partly visible in Figure 6, which had roof damage and interior water

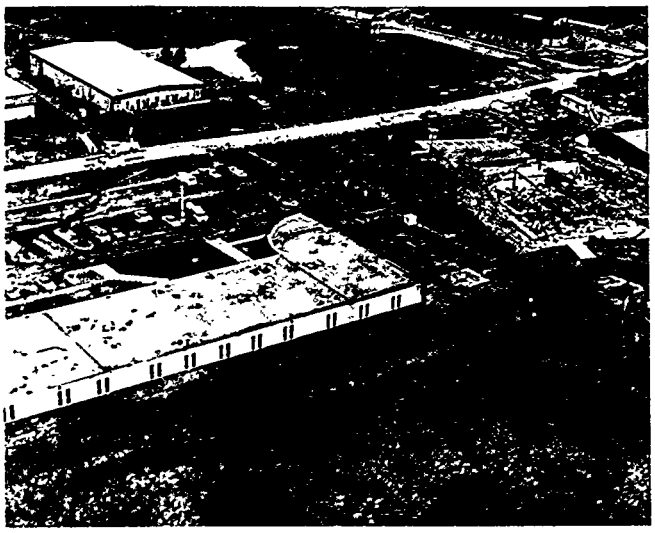

Figure 6. Union Valley Road Damage

damage. The west end of the City of Oak Ridge Incubator Building (the city maintains this facility to support the startup of small businesses) on the northwestern portion of the industrial park was destroyed. The Incubator Building is basically a light steel frame structure with metal siding. The tornado struck the far west end of the structure, destroying 20 ft of the building, then skipped over the remainder of the building, causing little more damage to the rest of the building and its contents. Some exterior heating units were blown away from the building. A TVA transmission tower located on a small hill behind the Incubator Building was knocked down. Other buildings in the area received varying amounts of damage. ZYP Coating had a roll up door blown inside, roof and facade damage, and broken windows. Ogden Environmental had exterior damage on the east side, roof damage, internal water damage, and moderate damage to vehicles parked in the rear. Maxima had some roof damage and interior water damage. Mid City Tool had west wall damage, some roof and water damage, and heating units that were moved and damaged. Ebasco suffered roof damage, broken windows, and scattered debris. Similar damage occurred to other buildings in this area. There was also a propane gas leak at the City of Oak Ridge's Peak Shaving Plant.

The FEDC Building, leased by Energy Systems, houses personnel for a number of projects, including the Advanced Neutron Source (ANS), the International Thermonuclear Experimental Reactor Project, and the Superconducting Super Collider. Approximately one-third of the west end of the FEDC built-up roof was blown off, allowing water and wind to enter the building and damage many offices in that end of the building. Water-logged ceiling tiles fell on desks and computer systems, and many items such as computer components, books, and cabinets were damaged by the water. Portions of the ceiling insulation were blown away. Sections of the built-up roof, including loose gravel, were scattered around the grounds. Five vehicles were badly damaged by the debris; two were total losses. One Energy Systems employee was in the building at the time of the event. He was not injured and remained to help mitigate the damages from water leaking through the roof. The structural frame to the FEDC was not damaged.

UT ARBORETUM AND HAW RIDGE PARK

The UT Arboretum, a local tourist attraction, offers a number of walking trails and plant and wildlife habitats for research, is located less than one mile east of the Y-12 Plant. It has 2260 acres situated along Pine Ridge and Chestnut Ridge. Approximately 500 acres were damaged by the tornado, mostly along the Chestnut Ridge area, of which 260 acres were completely destroyed [2]. Many trees were uprooted and broken. Most of the fallen trees were evergreens. In addition, some TVA power lines and transmission towers in the arboretum area were also blown down. The arboretum was temporarily closed after the tornado until the area could be cleared of debris and fallen trees. Haw Ridge Park, located east of the Arboretum and on the other side of and south of Bethel Valley Road, extends to the Clinch River to the east and south. The tornado also inflicted heavy damage to trees in this area. Figure 7 shows damaged trees and, in the center of the picture, a downed TVA transmission tower. The Bull Run Steam Plant is seen across the Clinch River.

COMMUNITY OF CLAXTON

Claxton was the hardest hit residential community in Anderson County. It is located in an area south and also northeast of the TVA Bull Run Steam

Plant. Residential homes, power lines, and hundreds

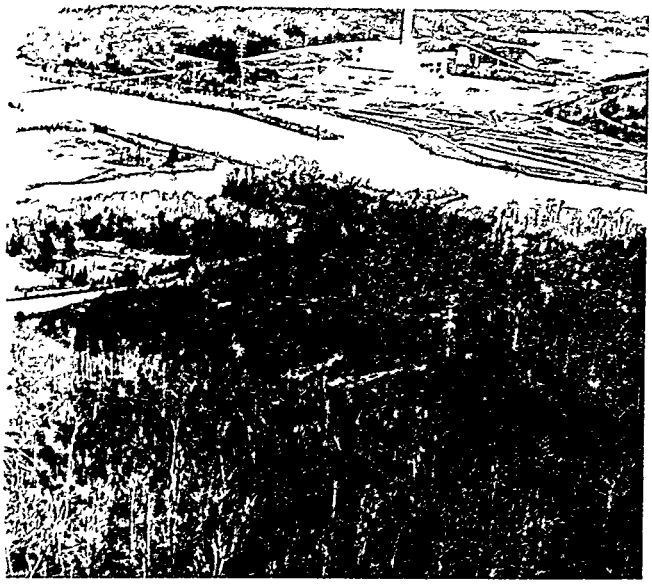

Figure 7. Haw Ridge Park Damage

of trees were damaged and/or destroyed (Fig. 8). A number of trailers were damaged. Many houses, garages, and barns suffered roof and miscellaneous exterior wall damage; several homes were destroyed - one house had the third floor completely demolished.

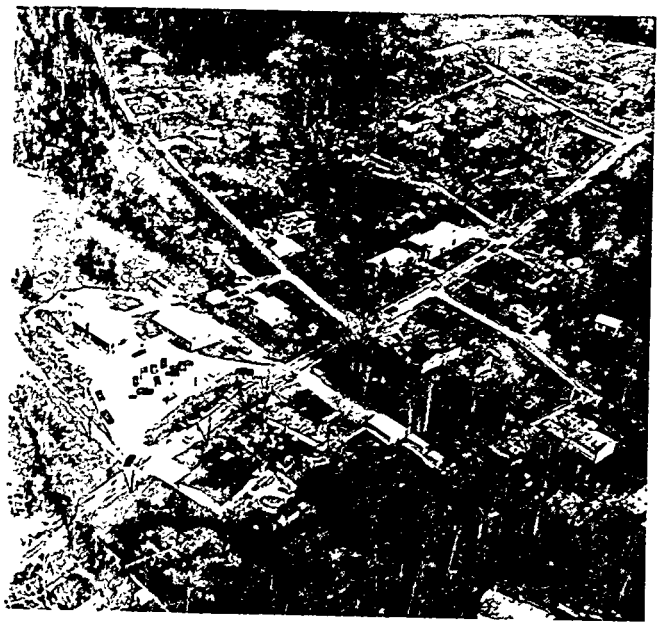

Figure 8. Damage in Claxton

The Steam Plant was shut down because some of the electrical transmission lines from the plant were knocked down; approximately 1500 homes in Claxton were without power, some for a number of days, following the storm. A trailer park located about 3 miles east of this area along Highway 25W (still part of Claxton) was struck by the tornado, some trailers were damaged, and a few minor injuries were reported.

TVA POWER LINES DAMAGE

The TVA electrical power transmission grid system in the Oak Ridge, Claxton, and Powell areas was damaged during the storm. Transmission lines out of the Bull Run Steam Plant were severely damaged. Fourteen H-frame poles and 11 laced steel towers (two on the 500-kV system), were severely damaged and/or knocked down [3]. Two 161-kV towers were in the Union Valley Road area and another five were between the Arboretum and the Steam Plant. Power was disrupted to a widespread area of Anderson and Knox counties, most of which was back in service by the following morning. Including damage in Lenoir City, TVA estimated damage costs to be $3 million.

Y-12 PLANT EMERGENCY RESPONSE AND RECOVERY TO THE TORNADO EVENT

RESPONSE ACTIVITIES

After the 2:26 pm tornado watch issued by the NWS, the Y-12 Plant Shift Superintendent (PSS) notified General Plant Maintenance supervisors of the severe weather conditions forecast and the site public address and radio system was used at various times during the day to keep onsite personnel aware of the weather situation. The Y-12 PSS used a natural hazards tornado checklist established in 1990 during a tabletop exercise in preparation for response and recovery actions (1). At 4:20 pm, the K-25 Site PSS notified the TSCA Incinerator of the approach of a severe thunderstorm as indicated on the K-25 Site thunderstorm monitoring system. The burning of all waste was suspended at the incinerator at that time (1). At 4:30 pm, the NOAA weather radio in the Y-12 PSS office was triggered and announced that severe thunderstorms were in progress in counties north of Y-12. At 4:39 pm, when the tornado hit the east end of the Y-12 plant,

a power failure occurred when a TVA 161-kV linepower feeding the Elza 1 Substation at Y-12 was blown down. A circuit breaker opened and interrupted power to several buildings, including the Steam Plant, Steam Plant Wastewater Treatment Facility, and the Water Treatment Plant (operated by Johnson Controls World Services) which provides potable water to Y-12, ORNL, and the City of Oak Ridge. The east end of Bear Creek Road, the main entrance to Y-12, was blocked by debris and fallen power lines. A number of trees, signs, and utility poles along Bear Creek Road were blown down.

The Y-12 PSS began response activities. At 4:49 pm, TEMA notified the Laboratory Shift Superintendent (LSS) at ORNL of tornado sightings in the Oak Ridge area. The LSS notified the HFIR Control Room and at 5:06 pm the reactor was shut down. Shortly after the tornado passed by the plant, the Johnson Controls operator at the Water Treatment Plant, informed the Y-12 PSS that the Water Plant was without power, and requested assistance from the PSS to facilitate access by a utility crew from the city of Oak Ridge because normal access was blocked by debris and downed power lines. The Y-12 PSS arranged for access through the north side of the ridge. At 4:59 pm, NWS issued a tornado warning for Anderson County which includes the ORR and Y-12, and the Y-12 EOC was activated. No injuries were reported, no hazardous materials were released, and it was determined that there was no emission potential as a result of the power outage (1). The available members of the Y-12 EOC cadre responded to their pager and telephone notifications. Because of debris and fallen power lines, access to the Y-12 Plant was blocked to traffic approaching from the east, so many individuals had to detour and approach Y-12 from the west.

All Material Access Area and PIDAS alarms were operational. At 6:00 pm, additional Y-12 Security and Industrial Hygiene personnel were called in, and electrical maintenance crews were dispatched to restore plant power. Work shifts scheduled for rotation were held over until activities were stabilized. At 6:04 pm, the Y-12 EOC was declared operational and the Y-12 Crisis Manager assumed overall command of the incident. Power was restored to major buildings within two and a half hours after the power outage. At 9:41 pm, the Y-12 EOC was deactivated and operations returned to the control of the Y-12 PSS.

The DOE Oak Ridge Operations (ORO) EOC, located in the Federal Building in Oak Ridge, is staffed continuously. Staffing in the ORO EOC was augmented by various ORO officials after the tornado passed Y-12. ORO senior management and DOE Headquarters EOC were kept informed of weather-related activities through the ORO EOC. Each Oak Ridge site was contacted by the ORO EOC to confirm that there had been no injuries or releases of hazardous materials. This status information was passed to TEMA along with the offer to make DOE resources available, if necessary, to support response in the surrounding communities.

Y-12 officials were in continuous contact with the city of Oak Ridge and utility officials throughout the event. Mutual aid was requested and promptly provided by the City of Oak Ridge, the Tennessee Highway Patrol, K-25 Site, ORNL, TVA, Johnson Controls, and MK-Ferguson. This aid included law enforcement traffic control, power restoration, and equipment loan. The Y-12 Security Patrol Department provided traffic control mutual aid to the Oak Ridge Police Department in the vicinity of Y-12.

Emergency power was provided to critical facilities at Y-12 during the power outage. Twenty-nine of the 30 required emergency power generators started and supplied building power to critical safety systems. The one which failed to start supplies emergency power to Building 9616-7 systems. The building (a satellite maintenance shop) was unoccupied at the time of the tornado, and its function was determined to be noncritical to the recovery operation.

Because the warning came after the tornado hit the plant, the precautionary measures taken during the two hours after the tornado watch was announced and preceding the power failure and the tornado warning were appropriate. The emergency response to the incident was well executed. Plant operations were returned to normal in less than 8 hours.

RECOVERY ACTIVITIES

The recovery operations proceeded in a timely and safe manner. The Y-12 EOC was activated and the necessary support crews called to the plant. Industrial Safety engineers were also called in to participate in the recovery operation planning and execution. A medical team was brought to the site ready to assist should injuries be incurred or other medical emergencies arise. No recordable injuries or first aid cases were experienced as a result of the tornado or during recovery efforts. Damage control elements in the Y-12 Plant area experienced some difficulties in communicating information to the EOC (1). The communications interface with mutual aid responders was also not fully effective.

Damage assessment activities continued through the night. A detailed damage assessment was initiated the morning after the incident. A Recovery Actions Coordinator was named to oversee the repairs, to minimize the disruption to normal operations, and to optimize the use of plant resources in performing the restoration activities.

On Monday access to the Union Valley Industrial Park was closed except to property owners. Access to the east end of the Y-12 Plant was limited. Information regarding the limited access was broadcast over local radio and television stations. Many employees and local residents were forced to detour around the area and take alternate routes to work. The rerouting of traffic caused numerous people to be delayed up to several hours.

DISCUSSION OF TORNADO WIND SPEEDS

The Y-12 Plant has two meteorological towers on site, a 60-m tower near the west end, and a 100-m tower at the east end. The west tower, located away from the tornado track, was unaffected by the storm passage, but the tornado passed within a few meters of the east tower. Wind speed data from the east tower, which was undamaged by the passage of the tornado, are for 15-min averages. The highest 15-min average speed recorded was approximately 30 mph. Given the small size of the tornado at this location (based on eyewitness accounts as well as the extent of the damage), the peak winds were of such short duration as to be damped out by the averaging time. Therefore, these data cannot be used to accurately determine the tornadic wind speeds. A meteorological tower at the National Oceanic and Atmospheric Administration's (NOAA) Atmospheric Turbulence and Diffusion Division (ATDD) located approximately half a mile northeast of Y-12 and not in the direct path of the tornado, measured a peak gust of 70 mph. No significant changes in barometric pressure were measured at either site.

The Fujita or F-scale [4] is a simple method for estimating wind speeds, and it allows a quick classification for each of the hundreds of tornados that occur every year. This scale is divided into 13 segments, F-0 through F-12 (though only F-0 through F-5 have been used for measuring tornado speeds). While simple to use, it also has some drawbacks [5].

The news media indicated damage to the local area as being caused by wind speeds as high as 200 mph, but review of the damage to the commercial and residential districts, as well as to the UT Arboretum and other heavily forested areas, does not support wind speeds that high when compared to the F-scale descriptions. The Knazovich study [1] concluded that the majority of damage observed at the Y-12 Plant resulted from an F-0 tornado (40-72 mph), with an F-1 category tornado (73-112 mph) being responsible for the most severe damage. Most damage in the plant is to trees and to poles that were either knocked down or snapped, to signs, and to other relatively small items. Small areas of roofs were peeled off, and empty storage tanks were pushed approximately 20 ft. The only damages to major engineered facilities at the Y-12 Plant were architectural in nature; no damage to the structural frames occurred. The report stated that the damage to the Y-12-to-Claxton community can be categorized as being caused by an F-0 or F-1 tornado, with perhaps the lower end of an F-2 tornado being responsible for some of the damage in the forested areas and Claxton. Thus, wind speeds from this tornado event ranged from 40 mph at the lower end to as high as maybe 130 mph.

RISK-BASED APPROACH TO SEVERE WEATHER DESIGN AND PLANNING

A key objective of DOE's emergency management program is to ensure that all DOE facilities and operations develop and maintain emergency planning, preparedness and response capabilities, as well as effective public and interagency communications, to minimize the consequences to workers and the general public from events involving the release of hazardous materials. If planning and preparedness for emergencies are to be adequate and appropriate, then the hazards that are specific to each facility and operation must first be identified and understood.

The East Tennessee region, including the Oak Ridge area, has one of the lowest incidences of tornadoes east of the Rocky Mountains. Numerous methods of calculating tornado frequencies and recurrence intervals exist. A common approach is that initially proposed by Thom [6]. Based upon historical tornado sightings over a large (1°) square, a point probability can be calculated. The probability of a point, like the Y-12 Site, being struck by a tornado of any magnitude is approximately 0.0004. The recurrence interval for a tornado striking that point is 1/0.0004, or once every 2500 years. This value is only approximate, and is derived from averaging the nearest one degree squares. An approach first proposed by Abbey and Fujita [7] is to regionalize the hazard of tornadoes, including the intensity of the tornado damage. Site-specific studies by Fujita [8,9], McDonald [10], and Beavers et al. [11] were performed for the ORR. McDonald used data from the weather station at the Knoxville airport to obtain his straight wind curves, whereas Fujita and Beavers used the local data base (dating from the 1940s) from NOAA. All three used site-specific data for the tornado curves. The Beavers study was adopted by the ORO in 1985 as its position with respect to high wind hazards for the evaluation of existing, and for the design of new, nonreactor nuclear facilities. More recently the UCRL-15910 [12] guidelines have been used, though with respect to tornado winds there is no difference. Based on these studies, the probability of a tornado with wind speeds of 100 mph occurring at Oak Ridge is about 5×10^{-5}, or a recurrence interval of about once every 20,000 years. The probability of a significant tornado (F-2 or higher) striking the Oak Ridge area ranges between 3×10^{-5} to 1×10^{-7}. UCRL-15910 recommends a tornado wind speed of 113 mph be used for design and analysis for Category 2 facilities in the ORR, which is the hazard classification for the Production facilities in Y-12. In addition to the wind speeds, UCRL-15910 specifies that wind-generated missiles be considered. For facilities with a lesser hazard classification, a 70-mph straight wind speed is given for design and analysis, with no missile analysis required. Based on the wind speeds estimated, it is concluded that the tornado that touched down near Y-12 had essentially the UCRL-15910 design tornado winds (without the wind-generated missiles).

Understanding the vulnerability of facilities and buildings to natural phenomena has been an ongoing effort of the Y-12 Plant since the early 1970s. Design codes have changed over the years and wind load criteria have become more stringent. In the Y-12 Plant the main production facilities are large, fully engineered structures, comprised of a steel or reinforced concrete frame, with reinforced concrete floor slabs and unreinforced URM hollow clay tile, brick, or concrete block infill (generally spanning column to column and floor to roof) walls. Roofs are reinforced concrete slabs, precast channel slabs supported by roof purlins, or metal decking supported by joists, all overlain with some form of gypsum or built-up roofing. URM walls form both exterior and interior walls. Most of these buildings were originally built in the 1940s and 1950s, and all of them have had modifications to the walls and roofs. A number of smaller structures consisting entirely of URM construction or wooden construction and a few light, prefabricated metal-siding types of buildings also exist. A few office facilities of more recent vintage (1970's or later) exist. In addition to the main structures, tank farms and pipelines are located outdoors in the Production area. Similar types and variations of constructed facilities exist toward the east end of the plant, except that the buildings are generally not as large as those in the Production area, and trailers (used for offices), and wooden construction is more prevalent.

Since 1990, the Y-12 Plant has had a major evaluation and testing program to study the strength and behavior of the hollow clay tile infill walls that

are commonly found in the major production facilities. Laboratory and in situ testing of the hollow clay tile walls has been performed. The results of this program have provided great insight into the performance of buildings at Y-12 when subjected to both seismic and extreme wind loads.

Were the main production buildings to undergo a direct strike by a moderate tornado (i.e., an F-1 or F-2 tornado having wind speeds of 73 to 157 mph), damage to the built-up roofs (such as spalling and/or possible sections uplifting) and to some walls would result. It is not expected, however, that walls would collapse or be blown out by this tornado. Recent tests of hollow clay tile infill walls by Fricke et al. [13] and Flanagan et al. [14] have shown that these walls are able to easily withstand lateral pressures beyond 1 psig, that translate to straight wind speeds in excess of 200 mph. Tornado-generated missiles (pipes and debris), however, would easily penetrate URM boundary walls. McDonald and Bailey [15] and Nevins [16] have shown that unreinforced concrete masonry barriers are easily penetrated by wind-generated 2 by 4-in. timber plank missiles. Three-inch-diameter steel pipe missiles are even more difficult to stop. The openings to the buildings from the damaged roofs and any penetrations of the wall would permit water and winds to enter the facility, which in turn could damage mechanical equipment and offices inside. It is not expected that the structural frame or the floor slabs would be seriously damaged by a tornado of this magnitude.

Consequences of a direct tornado strike to the smaller, lighter structures would be severe to both the structure and its contents. Obviously, trailers are prone to being seriously damaged and overturned during tornadoes. Standard wooden construction, as seen by the damage in Claxton and Lenoir City, does not stand up well under tornadic loads, but again there is very little of this type of construction at Y-12. Where such construction exists, the buildings were built in the 1940s and early 1950s and are primarily used for office space. It could be expected that roofs would be damaged, if not completely lifted off, opening the inside to the storm. Small buildings constructed with unsupported, load-bearing URM side walls might be significantly damaged. As these structures are damaged, more debris and tornado-generated missiles would be created. Tanks and pipelines located outside of facilities would be vulnerable to wind-generated missiles, and, depending on the capacity of the tie-downs, would be susceptible to being moved or thrown about.

Analysis of accidents in facilities at Y-12 is documented in Safety Analysis Reports (SARs). The SARs are presently being updated in an SAR Update Program (SARUP). SARUP was designed to be a risk-based, graded approach by prioritizing the schedule and facilities to be analyzed by hazard category. In addition, at the end of each phase of the program an evaluation is made to determine if any risk-reduction actions should be incorporated into the facility, process, or procedures to lessen the risk to workers or to the public. Changes that involve substantial employee or public health and safety improvements are made according to their priority as defined by the level of danger to on-site personnel or to the public. For operating areas, a cost/benefit technique is used on modifications that involve improvements of a lesser health and safety magnitude. Severe natural phenomena (tornadoes, earthquakes, or floods) are considered in light of their potentials as initiating events. Some of the tornado-initiated accidents analyzed in SARs include personal injury, release of hazards, and criticality. Minor releases of material beyond the Y-12 boundary are possible in the event of a severe accident initiated by a tornado at a Y-12 facility, but no off-site exposure to toxic or radiological materials, with irreversible health effects, should occur. The probability of an accidental nuclear criticality caused by a tornado event at Y-12 is extremely low, with a probability of occurrence significantly less than 10^{-5} per year.

CONCLUSIONS

An F-0 to F-1 tornado struck near the Y-12 Plant, causing minor damage to facilities, power lines, utility poles, vehicles, and trees and signs. The tornado continued for about 13 miles causing further damage along its path. Existing site emergency plans and procedures were followed. The Y-12 EOC was activated, and response personnel were mobilized. No injuries occurred, no hazardous materials were released, and it was determined that no hazardous material release potential existed as a result of the power outage. Analyses of building resistance to

wind and seismic loadings have been conducted for a number of key Y-12 facilities since the 1970s. Recent studies conclude that building construction with infill URM walls have a higher resistance to strong winds than determined in the early studies, based on new test data and analysis methodologies.

REFERENCES

1. Knazovich, M.W., Beavers, J.E., DeRossett, W.J., Johnson, P.L., Kornegay, F.C., and Merrill, A.R., Tornado Special Study Report, ES/ESH-35, Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee, June, 1993.

2. Wilkinson, M., "Tornadoes in the Lab," The Knoxville News-Sentinel, May 3, 1993, p. B.1.

3. Cann, N., "TVA Crews, Officers, Help Weather Storms," Inside TVA, Vol. 14, No. 5, March 9, 1993, pp. 1, 3.

4. Fujita, T.T., Proposed Characterization of Tornados and Hurricanes by Area and Intensity, SMRP Res. Paper No. 91, University of Chicago, Chicago, Ill., 1971.

5. Liu, H., Wind Engineering, Prentice-Hall, Englewood Cliffs, New Jersey, 1991.

6. Thom, H.C.S., "Tornado Probabilities," Monthly Weather Review, Vol. 91, Nos. 10-12, 1963, pp. 730-736.

7. Abbey, R. F. and Fujita, T. T., "Regionalization of the Tornado Hazard," Proceedings 10th Conference on Severe Local Storms, held in Omaha, Nebraska, October 18-21, 1977, American Meteorological Society, Boston, Massachusetts, 1977, pp. 526-533.

8. Fujita, T.T., Tornado and High Wind Risks at Oak Ridge National Laboratory, Tennessee, prepared for Lawrence Livermore Laboratory, Livermore, California, 1979.

9. Fujita, T.T., Additional Studies on Oak Ridge, prepared for Lawrence Livermore Laboratory, Livermore, California, 1980.

10. McDonald, J.R., Assessment of Tornado and Straight Wind Risks at the Oak Ridge, Tennessee Site, prepared for Lawrence Livermore Laboratory, Livermore, California, 1979.

11. Beavers, J.E., Hammond, C.R., and Manrod, W.E., Recommended Straight Wind, Tornado, and Wind-Generated Missiles Hazards for the Oak Ridge, Tennessee; Paducah, Kentucky; Fernald, Ohio; and Portsmouth, Ohio Department of Energy Reservations, Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee, 1985.

12. Kennedy, R.P., Short, S.A., McDonald, J.R., McCann, M.W., Murray, R.C., and Hill, J.H., Design and Evaluation Guidelines for Department of Energy Facilities Subjected to Natural Phenomena Hazards (UCRL-15910), prepared under the auspices of Lawrence Livermore National Laboratory, Livermore, California, June, 1990.

13. Fricke, K.E., Jones, W.D., and Huff, T.E., "In Situ Lateral Load Testing of an Unreinforced Masonry Hollow Clay Tile Wall," Proceedings 6th Canadian Masonry Symposium, Saskatoon, Saskatchewan, Canada, June, 1992, pp. 519-530.

14. Flanagan, R.D., Bennett, R.M., Burdette, E.G., and Goodpasture, D.W., "Testing of Clay Tile Infilled Frames," Proceedings National Workshop on Unreinforced Hollow Clay Tile held in San Francisco, California September 21-22, 1992, sponsored by the Office of Environment, Safety, and Health, U.S. Department of Energy, ES/CNPE-93/1, 1993, pp. 197-201.

15. McDonald, J.R. and Bailey, J.R., "Impact Resistance of Masonry Walls to Tornado-Generated Missiles," Proceedings Third North American Masonry Conference, Arlington, Texas, 1985, pp. 84-1 to 84-11.

16. Nevins, N.B., Experimental Basis for Tornado-Generated Missile Impact Resistance Criteria, Masters Thesis, Department of Civil Engineering, Texas Tech University, Lubbock, Texas, 1993.

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