Impact of the 2004 Atlantic Hurricane Season on U.S. Nuclear Power Plants

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ABSTRACT

As part of its program to review and use operating experience, the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research, conducts long-term studies of selected topics. The main purposes of this study are (1) to collect and document information concerning Atlantic hurricanes, in general, and their specific impact on U.S. nuclear power plants in 2004, and (2) to share this information both internally and with stakeholders.

This study identified Brunswick Steam Electric Plant, St. Lucie Plant, and Crystal River Nuclear Generating Plant as the three plant sites that were impacted by hurricanes in 2004. With that knowledge, this study focused on understanding hurricane preparations by the NRC and its licensees, as well as storm effects on the plants and any hurricane-related corrective actions or lessons learned documented in the related event notifications, preliminary notifications, inspection reports, and licensee event reports.

In general, this study revealed that hurricane preparations by the NRC and its licensees were effective. Although the hurricanes disrupted operation of the impacted NPPs, they did not have a significant impact on nuclear safety. The reportable impacts on the NPPs were mainly confined to the three areas of complete or partial loss of offsite power (LOOP), loss of sirens, and loss of communications equipment. Of these, LOOP is the most risk-significant, although loss of sirens or communications equipment could hinder emergency response to an event.

The site preparations and hurricane impacts, including the affected equipment, contributing causes, and licensees' corrective actions, may all provide useful insights for other plant sites in preparing for future hurricanes or other severe weather conditions.

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ABBREVIATIONS

BWR	boiling-water reactor
CFR	*Code of Federal Regulations*
EDG	emergency diesel generator
EN	event notification
ENS	emergency notification system
ERDADS	Emergency Response Data Acquisition and Display System
ERDS	Emergency Response Data System (NRC)
ERO	emergency response organization
HPCI	high-pressure coolant injection
INPO	Institute of Nuclear Power Operations
LER	licensee event report
LOOP	loss of offsite power
MSL	mean sea level
NOAA	National Oceanic and Atmospheric Administration
NPP	nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
NWS	National Weather Service
PCB	power circuit breaker
PWR	pressurized-water reactor
RAB	reactor auxiliary building
RCIC	reactor core isolation cooling
RES	Office of Nuclear Regulatory Research (NRC)
SBCS	steam bypass control system
SIT	special inspection team
UFSAR	updated final safety analysis report

EXECUTIVE SUMMARY

As part of its program to review and use operating experience, the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), conducts long-term studies of selected topics. The main purposes of this study are (1) to collect and document information concerning Atlantic hurricanes, in general, and their specific impact on U.S. nuclear power plants (NPPs) in 2004, and (2) to share this information both internally and with stakeholders.

To study the effects of the 2004 hurricanes on the Nation's nuclear power plants, the RES staff collected relevant operating experience to identify the impacted sites. Toward that end, the staff identified the impacted sites by reviewing event notifications and preliminary notifications that the Commission received under Title 10, Section 50.72, of the *Code of Federal Regulations* (10 CFR 50.72) for the dates associated with each of the four hurricanes of interest (Charley, Frances, Ivan, and Jeanne). In so doing, the staff identified Brunswick Steam Electric Plant, St. Lucie Plant, and Crystal River Nuclear Generating Plant as the three impacted plant sites. The staff then conducted detailed reviews of all related inspection reports for the appropriate time frame, as well as all 2004 licensee event reports (LERs) from these three sites. This review focused on understanding hurricane preparations by the NRC and its licensees, as well as storm effects on the plants and any hurricane-related corrective actions or lessons learned, as documented in the notifications or reports.

In general, this study revealed that hurricane preparations by the NRC and its licensees were effective. Although the hurricanes disrupted operation of the impacted NPPs, they did not have a significant impact on nuclear safety. NPPs are robust facilities, which are designed to withstand the impact of severe weather, such as hurricanes. The three main factors that limited the safety impact of the 2004 hurricanes were the plants' robust design, successful operation of emergency diesel generators (EDGs) during the events, and the limited extent or duration of the associated losses of offsite power (LOOPs).

As a result of these factors, the reportable impacts of the 2004 hurricanes on the Nation's NPPs were mainly confined to the three areas of complete or partial LOOPs, loss of sirens, and loss of communications equipment. Of these, LOOPs are the most risk-significant, although losses of sirens or communications equipment could hinder emergency response to an event.

The site preparations and hurricane impacts, including the affected equipment, contributing causes, and licensees' corrective actions, may all provide useful insights for other plant sites in preparing for future hurricanes or other severe weather conditions.

1. INTRODUCTION AND BACKGROUND

As part of its program to review and use operating experience, the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), conducts long-term studies of selected topics. The main purposes of this study are (1) to collect and document information concerning Atlantic hurricanes, in general, and their specific impact on U.S. nuclear power plants (NPPs) in 2004, and (2) to share this information both internally and with stakeholders.

1.1 General Background on Hurricanes

A hurricane is a tropical cyclone with winds of 74 miles per hour (mph) or greater that is usually accompanied by rain, thunder, and lightning and that sometimes moves into temperate latitudes. The National Weather Service (NWS) designates June 1 through November 30 as the official "hurricane season," with August and September generally being the peak months. The NWS uses the Saffir-Simpson Hurricane Scale to categorize hurricanes, with Category 1 being the least severe (with wind speed of 74–95 mph and a storm surge of 4–5 feet), and Category 5 being the most severe (with wind speed greater than 155 mph and a storm surge greater than 18 feet). Based on this categorization, Category 3, 4, and 5 hurricanes are considered to be "major hurricanes," which are of greatest concern to NPPs (Ref. 1). The appendix to this report provides additional detail on the Saffir-Simpson Hurricane Scale.

Flooding associated with hurricane storm surge typically causes the most damage and most loss of life, and the extent of evacuation is generally based on the predicted storm surge (Ref. 1). Hurricanes can also generate tornadoes, heavy rainfall and associated flooding, and wind damage. The flooding and wind damage can result in power outages, blocked roads, and other problems that can disrupt normal activities and hinder emergency response. State and local governments typically order evacuations from coastal and other low-lying areas that are likely to be severely impacted by a hurricane.

With modern hurricane prediction and tracking, it is almost certain there will be time to prepare for the arrival of any particular hurricane. However, some hurricanes are remarkably unpredictable. For example, in 1984, Hurricane Diana headed directly away from Brunswick Steam Electric Plant in North Carolina less than 18 hours before it hit the site (Ref. 1). Similarly, in 2004, Hurricane Charley showed that a small, late course change can cause a hurricane to make landfall where complete preparations have not been made.

1.2 Atlantic Hurricane Cycles and Implications for the Future

A literature search conducted as part of this study revealed that hurricanes may be a more significant societal issue in the future. The following factors are causes for concern:

(1) There is general scientific consensus that Atlantic hurricanes follow several cycles, with the main one being a 20–40-year cycle. These cycles relate to oscillations in the Atlantic and Pacific Oceans. In 2001, scientists concluded that an "up cycle" began in 1995 (Ref. 2).

(2) Recent scientific studies conclude that atmospheric changes have resulted in more or larger hurricanes in the past 35 years (Refs. 3 and 4). The mechanism is not fully

understood, but “warm cycles” are less conducive to wind shear than “cool cycles.” This is significant because wind shear acts to prevent hurricanes from growing, or may even disrupt them (Ref. 2). In addition, the atmosphere holds 5 percent more water today than it did a mere 15 years ago, thereby providing fuel for bigger, wetter storms (Ref. 5). Nonetheless, other scientists and experts strongly disagree that “global warming” has had any impact on hurricane frequency or intensity (Refs. 6 and 7). Despite this disagreement, the fact that scientists from reputable institutions have concluded that we are now experiencing more or larger hurricanes is cause for increased concern.

(3) Some scientists have concluded that last year’s extensive tropical activity (including the Florida hurricanes and typhoons striking Japan) related to persistent large-scale circulation features that steered the systems toward land. It is unclear how global warming will affect these circulation patterns (Ref. 8), but the main concern is the possibility that steering current changes will result in more hurricanes making landfall.

(4) Major hurricanes (Categories 3, 4, and 5) account for only 20 percent of all hurricanes, yet they account for 80 percent of hurricane damage because larger hurricanes typically cause more damage than small hurricanes (Ref. 2).

(5) The east coast of the United States has been “lucky.” In 1995–2001, only 3 of the 26 major Atlantic hurricanes hit the United States with wind speeds of 110 mph or more (Ref. 2).

(6) Population growth has occurred in U.S. coastal areas. In 2001, nearly 41 million people lived along the hurricane-prone coasts of the United States (Ref. 2).

(7) Each of the four hurricanes (Charley, Frances, Ivan, and Jeanne) that hit Florida within a 6-week period in 2004 was among the 10 costliest in U.S. history at the time (Ref. 9).

(8) Hurricane evacuations can challenge the transportation system. For example, as Hurricane Ivan approached New Orleans, Louisiana, in 2004, an estimated 600,000 evacuees fleeing New Orleans clogged highways, making the 80-mile trip to Baton Rouge a 10-hour ordeal (Ref. 10).

(9) Hurricanes can have a significant, widespread impact. For example, immediately following Hurricane Frances, more than 3.4 million customers across 62 counties in Florida were affected by power outages. Twelve days later, 16,500 customers in 6 counties were still without power, despite the fact that more than 15,000 customers and 10 counties had been fully restored over the preceding 24 hours (Ref. 11). The experience with Hurricane Katrina in 2005 underscores this point.

1.3 Hurricane Damage to a Nuclear Power Plant

Although NPPs are robust facilities and are designed to withstand the impact of severe weather, such as hurricanes, a direct hit by a “major“ hurricane to a coastal NPP can cause significant damage to nonessential structures, systems, and components, as evidenced by Hurricane Andrew in 1992. Hurricane Andrew was initially considered a Category 4 hurricane at its landfall near the Turkey Point Nuclear Generating Station in Florida, but it has been reclassified by the National Hurricane Center as a Category 5 hurricane. The NRC and the Institute of Nuclear Power Operations (INPO) reviewed the resultant damage, which they documented in a

joint report, entitled “Effect of Hurricane Andrew on the Turkey Point Nuclear Generating Station from August 20–30, 1992,” which was issued in March 1993 (Ref. 1). Hurricane Andrew was somewhat of an anomaly in that wind, rather than flooding, did most of the damage. Prior to Hurricane Katrina in 2005, Hurricane Andrew was the top U.S. Atlantic hurricane in terms of damage at nearly $35 billion in 2000 dollars, more than double the next costliest hurricane (Ref. 9).

The damage attributable to Hurricane Andrew at Turkey Point constitutes the best available operating experience information regarding actual damage from a direct, major hurricane strike at a U.S. NPP. Reference 1 also contains detailed descriptions and numerous photographs of the hurricane damage at Turkey Point, which included the following impacts:

(1) The nuclear portion of the plant, contained within Class I structures, suffered no damage except for minor water intrusion and some damage to insulation and paint.

(2) All offsite power was lost during the storm and for over 5 days.

(3) All offsite communications were lost during the storm for about 4 hours, and the access roads to the plant were blocked with trees and utility poles.

(4) Nonnuclear Class III structures, systems, and components suffered some damage, most of which occurred when the 100,000-gallon water tower collapsed, destroying a raw water tank and portions of the fire protection system piping, and disrupting the city water supply system. Electrical service and instrumentation associated with the equipment struck by the water tower were also destroyed, rendering the fire protection system inoperable.

(5) The security system sustained extensive damage to equipment such as a lighting, cameras, intrusion detection equipment, protective area fencing, and the entrance building.

(6) Numerous outlying facilities and buildings were damaged. The Central Receiving Facility, containing a large spare parts inventory, received extensive structural damage.

(7) Significant effort was expended in providing food, temporary living quarters, and basic necessities to a number of employees and their families.

1.4 2004 “Florida” Hurricanes

Hurricane descriptions provided below are from the National Oceanic and Atmospheric Administration (NOAA) Web site, http://www.nhc.noaa.gov/HAW2/english/history.shtml, except where otherwise noted.

Hurricane Charley

Charley made landfall with maximum winds near 150 mph (Category 4) on the southwest coast of Florida just north of Captiva Island around 3:45 p.m. on August 13, 2004. An hour later, Charley’s eye passed over Punta Gorda. Charley then crossed central Florida, passing near Kissimmee and Orlando. Charley was still of hurricane intensity around midnight, when its center cleared the northeast coast of Florida near Daytona Beach. After moving into the Atlantic, Charley came ashore again near Cape Romain, South Carolina, about noon on August 14

as a Category 1 hurricane. The center then moved just offshore before making a final landfall at North Myrtle Beach, South Carolina. Charley then weakened to a tropical storm over southeastern North Carolina. Although ferocious, Charley was a very small hurricane at its Florida landfall, with its maximum winds and storm surge located only about 6–7 miles from the center. This helped minimize the extent and amplitude of the storm surge, which likely did not exceed 7 feet. Nonetheless, the hurricane's violent winds devastated Punta Gorda and Port Charlotte, and Charley also produced 16 tornadoes, although rainfall amounts were generally less than 8 inches. The total U.S. damage is estimated to be near $15 billion, making Charley the second costliest hurricane in U.S. history at that time. Given the strength of the hurricane and the resultant destruction, casualties were remarkably low, with Charley being directly responsible for 10 deaths in the United States.

Based on the related event notifications (ENs) that the Commission received under Title 10, Section 50.72, of the *Code of Federal Regulations* (10 CFR 50.72), Hurricane Charley did not have a significant impact on Florida's NPPs. However, the storm did impact the operation of the Brunswick site in North Carolina, as detailed in Section 2.1 of this report.

Hurricane Frances

Hurricane Frances' peak winds reached 145 mph (Category 4) on two occasions. Frances made landfall near Stuart, Florida, just after midnight on September 5, 2004, with 105-mph maximum winds (Category 2). Frances gradually weakened as it moved slowly across the Florida peninsula, became a tropical storm just before emerging into the northeastern Gulf of Mexico early on September 6, and then made a final landfall in the Florida Big Bend region that afternoon as a tropical storm. Frances produced a storm surge of nearly 6 feet at its Florida east coast landfall, and caused widespread heavy rains and associated freshwater flooding over much of the eastern United States, with maximum reported rainfall of more than 18 inches at Linville Falls, North Carolina. Frances was also associated with the outbreak of more than 100 tornadoes throughout the southeastern and mid-Atlantic states, and the storm resulted in seven deaths in the United States. U.S. damage is estimated at about $8.9 billion, more than 90 percent of which occurred in Florida.

Based on ENs received by the NRC, Hurricane Frances impacted the operation of the St. Lucie and Crystal River sites. Sections 2.2 and 2.3 of this report provide details of this impact.

Hurricane Ivan

Ivan was a Category 5 hurricane, with winds in excess of 160 mph on September 9, 2004, when it was in the Caribbean. Ivan made landfall as a major hurricane (Category 3) with sustained winds of nearly 120 mph on September 16, just west of Gulf Shores, Alabama. Ivan weakened as it moved inland, producing more than 100 tornadoes and heavy rains across much of the southeastern United States before moving to the Delmarva Peninsula. A remnant split off from Ivan, drifted south, and eventually became a tropical storm again. Ivan weakened before making its final landfall in southwestern Louisiana as a tropical depression. Ivan's storm surge completely overwashed the island of Grand Cayman, where an estimated 95 percent of the buildings were damaged or destroyed. Surge heights of 10–15 feet occurred along the Gulf coast during Ivan's first U.S. landfall, and peak rainfall amounts in the United States were generally 10–15 inches. U.S. damage is estimated at about $14.2 billion, the third largest total ever at the time, and the death toll in the United States was 25.

Based on ENs received by the NRC, Hurricane Ivan did not significantly impact the operation of any NPP.

Hurricane Jeanne

Early on September 26, 2004, the center of Jeanne's 60-mile-wide eye crossed the Florida coast near Stuart, at virtually the identical spot where Frances had made landfall 3 weeks earlier. Maximum winds at landfall were estimated to be near 120 mph (Category 3). Fortunately, Jeanne made landfall near low tide, and estimates of storm tide (the combination of normal tide level plus storm surge) ranged from 6–10 feet (Ref. 12). Jeanne weakened as it moved across central Florida, becoming a tropical storm near Tampa during the afternoon of September 26, and then weakening to a depression a day later over Georgia, and was still accompanied by heavy rain when the depression moved over the Carolinas, Virginia, and the Delmarva Peninsula. Jeanne produced extreme rain accumulations in Puerto Rico and Hispaniola, with nearly 24 inches reported in Vieques, Puerto Rico. Rains from the cyclone resulted in historic floods in Puerto Rico and deadly flash-floods and mud slides in Haiti, where more than 3,000 people died and roughly 200,000 people were left homeless. In the continental United States, Jeanne caused five deaths and damage estimated at nearly $6.9 billion.

Based on ENs received by the NRC, Hurricane Jeanne impacted the operation of the St. Lucie site. Section 2.2 of this report provides details of this impact.

2. EFFECTS OF THE 2004 HURRICANES ON NUCLEAR POWER PLANTS

To study the effects of the 2004 hurricanes on the Nation's nuclear power plants, the RES staff collected relevant operating experience to identify the impacted sites. Toward that end, the staff identified the impacted sites by reviewing event notifications and preliminary notifications that the Commission received under 10 CFR 50.72 for the dates associated with each of the four hurricanes of interest (Charley, Frances, Ivan, and Jeanne). In so doing, the staff identified Brunswick Steam Electric Plant, St. Lucie Plant, and Crystal River Nuclear Generating Plant as the three impacted plant sites. The staff then conducted detailed reviews of all related inspection reports for the appropriate time frame, as well as all 2004 licensee event reports (LERs) from these three sites. This review focused on understanding hurricane preparations by the NRC and its licensees, as well as storm effects on the plants and any hurricane-related corrective actions or lessons learned, as documented in the notifications or reports.

2.1 Brunswick 1 and 2

Brunswick 1 and 2 are boiling-water reactors (BWRs) with Mark 1 containments, located 2 miles north of Southport, North Carolina, on the Atlantic seacoast. From the Brunswick updated final safety analysis report (UFSAR), the once every 100 years extreme wind for the site is 135 mph. In addition, Class I buildings are designed to withstand 300-mph tornado winds, and the wind loadings for Class I buildings are elevation specific (i.e., 130 mph for 0–50 feet, 150 mph for 50–150 feet, and 180 mph for 150–400 feet). Also, from the Brunswick UFSAR, the surge stillwater level at the site is 22.0 feet mean sea level (MSL). The nominal plant grade results in 2 feet of water depth surrounding the plant during maximum surge conditions, and all of the safety-related structures are waterproofed to an elevation of 22 feet MSL. As previously stated, Hurricane Charley was a Category 1 hurricane when it impacted operation of the Brunswick site; however, Charley weakened to tropical storm status while it was still over southeastern North Carolina.

Impact of Hurricane Charley at Brunswick

The NRC received the following ENs[1] from Brunswick for the period from August 12 through August 15, 2004:

- EN #40951 on August 13, 2004. The licensee declared an Unusual Event attributable to a hurricane warning. No protective actions were required, no emergency facilities were activated, and no offsite assistance was required.
- EN #40953 on August 14, 2004. The licensee declared an Unusual Event at 1:08 p.m. attributable to a loss of offsite power (LOOP) at Brunswick 1, which occurred as a result of a lockout trip of the station's auxiliary transformer. The reactor automatically shut down, and all emergency diesel generators (EDGs) started and loaded. The licensee manually started the reactor core isolation cooling (RCIC) and high-pressure coolant injection

[1] Event Notifications are available through the NRC's public Web site at http://www.nrc.gov/reading-rm/doc-collections/event-status/event/.

(HPCI) systems for reactor level and pressure control. The licensee announced that emergency response organizations would be activated; however, no offsite assistance was required.

- EN #40954 on August 14, 2004. The licensee reported the automatic reactor shutdown of Brunswick 1 due to LOOP (see EN #40953 above). As of 3:47 p.m., the licensee had not determined the cause of the LOOP. The licensee also reported that the 1B standby gas treatment train tripped as a result of an overheat condition. Troubleshooting activities were in progress to determine the cause of the event and corrective actions.
- EN #40955 on August 14, 2004. At 7:05 p.m., the licensee reported that the function of several offsite emergency preparedness sirens had been lost as a result of adverse weather. The licensee reported that a peak of 25 out of 36 sirens located in Brunswick and New Hanover Counties had been lost; however, all but 6 sirens in Brunswick County had been restored. All siren inoperabilities were the result of power loss.
- Update to EN #40951 on August 14, 2004. The licensee terminated the hurricane warning Unusual Event at 2:03 p.m. after the hurricane warning was lifted.
- Update to EN #40953 on August 14, 2004. The licensee terminated the LOOP Unusual Event at 5:13 p.m. after restoring offsite power.
- EN #40958 on August 15, 2005. The licensee reported an inadvertent emergency siren actuation, which occurred on August 14 at 1:22 p.m. The siren was silenced at 1:41 p.m. on August 15.

On August 20, 2004, the NRC established a Special Inspection Team (SIT) to inspect and assess circumstances associated with the August 14th LOOP event at Brunswick 1. The SIT reviewed several equipment issues, which had been identified by the licensee's post-trip review, and identified no findings of significance. Reference 13 documents the SIT's inspection, which led to the following findings:

- The cause of the LOOP was the internal failure of a switchyard breaker (PCB 24B) as it responded to a line fault outside the unit's switchyard. The line fault occurred when an insulator supporting the B phase of a 230-kV Weatherspoon transmission line mechanically failed.
- The site switchyard design and configuration complied with General Design Criterion 17. The SIT noted that changes could be made in the switchyard configuration and some switchyard equipment, which could significantly reduce the unit's vulnerability to similar events. The licensee initiated efforts to review and evaluate enhancements.
- A load-shed permissive HGA relay on emergency bus 1 failed when the relay dust cover prevented the relay armature from actuating. As a result, several loads were not shed from the bus before EDG-1 picked up loads on that bus. Upon identifying the relay problem (many relay dust covers had been modified somewhat, apparently during original plant construction), the licensee corrected the problem, completed an adequate operability evaluation of EDG-1, and performed a common-cause analysis of the other EDGs.
- To verify that no other important HGA relays had mispositioned dust covers, the licensee examined a larger population of relays in other applications. Through this examination, the licensee identified a number of conditions that needed to be corrected, but none of those conditions would have prevented proper operation of any relay.

- The inspectors determined that the licensee had performed extensive troubleshooting to determine the cause of the B-train standby gas failure. The licensee determined that the failure to start was caused by actuation of the B train's fire protection lockout circuitry, but was unable to identify a specific component failure.

The licensee submitted an LER (Ref. 14) on the August 14, 2004, LOOP event. That LER provided some additional details and corrective actions, including the following statements:

- The failure of the insulator supporting the B phase of the 230 kV Weatherspoon transmission line initiated the sequence of events. The metal casting on the insulator broke due to extreme corrosion. The failed insulator has been replaced and the line restored to service. Visual inspections of transmission line support structures are performed annually. It is difficult to observe the area of the insulator affected by the corrosion. Based on lessons learned from this event, the insulator strings for the transmission lines in the corridor to the site will be replaced with an insulator design which is less susceptible to corrosion. Those insulator strings outside the corridor will be inspected and replaced as needed with the improved insulator design. The procedure for visual inspection of the insulators will be revised to incorporate more specific guidance related to corrosion of the metal casting components and replacement of degraded insulators.
- PCB 24B failed due to an internal bushing failure, which resulted in current flashover within the breaker. The bushing failure is attributed to moisture intrusion. The root cause of this event is attributed to an inadequate power circuit breaker (PCB) maintenance process. Specifically, preventive and corrective maintenance had not identified the adverse trend of moisture build up in the bushings as a problem requiring corrective action. The degraded bushing was replaced and PCB 24 restored to service. Preventive and corrective maintenance processes will be revised to establish adequate measures for identifying and trending moisture intrusion in PCBs and ensure timely accomplishment of needed corrective actions.
- The cause of the event was attributed to a combination of conditions involving the failure of PCB 24B and switchyard breaker scheme in effect at the time. As corrective action, the breaker scheme on both units has been aligned such that the station auxiliary transformer is connected to the non-preferred bus, and applicable plant procedures will be revised to reflect the new preferred breaker scheme.
- To address the load shed issue with EDG-1, an Engineering Change was approved to allow HGA surface mounted relay covers to be removed. HGA surface mounted relays on all 4.16-kV emergency buses were inspected for similar conditions, and some non-desirable cover conditions were identified, none of which represented an additional operability concern. Training to ensure that all appropriate maintenance personnel are aware of modified HGA relay covers and their potential for mis-positioning was planned.

Hurricane Preparations and Related Inspection Activities at Brunswick

During the approach of Hurricanes Charley and Frances to the Cape Fear Region of North Carolina, the NRC resident inspectors attended hurricane preparation status meetings, reviewed site preparations for adverse weather, and reviewed preparations for plant damage assessment. The inspectors toured risk-significant and susceptible plant areas to verify the implementation of adverse weather preparation procedures and compensatory measures before the onset of adverse weather conditions. The inspectors also documented walkdowns and review of analyses associated with internal and external flooding. (Ref. 15)

The inspectors observed the operator response to the August 14 LOOP event. The inspectors also reviewed an operability evaluations associated with the improper load stripping of EDG-1 and HGA relay covers. The inspectors followed post-maintenance testing associated with the 1B standby gas treatment train which failed on August 14. No findings of significance were identified. (Ref. 15)

2.2 St. Lucie 1 and 2

St. Lucie 1 and 2 are Combustion Engineering pressurized-water reactors (PWRs) with dry ambient containments, located 12 miles southeast of Fort Pierce, Florida, on the Atlantic seacoast. From the St. Lucie 2 UFSAR, the once every 100 years extreme wind for the site is 120 mph, and Class I buildings are designed to withstand 300-mph tornado winds and a design hurricane wind speed of 194 mph. Also, from the St. Lucie UFSAR, reinforced concrete flood walls have been provided around structures in the plant to an elevation of +22 feet mean low water level ocean. The maximum calculated wave runup coincident with the maximum peak surge level is below the plant grade elevation of +18.5 feet and below the minimum elevation of +19.5 feet of any building openings. As previously stated, Hurricanes Frances and Jeanne impacted operation of the St. Lucie site, with winds of 105 mph and 120 mph, respectively, at landfall.

The NRC received the following ENs from St. Lucie for the period from September 2 through September 5, 2004, for Hurricane Frances:

- EN #41006, on September 2, 2004. The licensee declared an Unusual Event at 10:43 a.m. in response to a hurricane warning in effect.
- Update to EN #41006 on September 3, 2004. The licensee reported at 8:35 p.m. that Unit 1 was being down-powered [and would be taken] off line, and Unit 2 would commence to down-power at about 9:00 p.m. in preparation for the storm. Both units were expected to be off line by midnight.
- EN #41018 on September 4, 2004. The licensee reported that at 1:56 a.m. a manual trip of Unit 2 occurred as a result of steam generator level oscillations while reducing power. The swings in the B steam generator were caused by erratic operation of the B feedwater regulating valve. All primary and secondary systems functioned as expected, with the exception of the steam bypass control system (SBCS). The SBCS consists of five pressure control valves, PCV-8801 through PCV-8805, with PCV-8801 a larger capacity valve and designed to open first. The remaining valves are designed to open in series, with overlap through their operating ranges. PCV-8801 failed to open and PCV-8802,

8803, and 8804 did not appear to properly control reactor coolant system temperature. PCV-8805 was operated manually to control steam generator pressure.

- EN #41019 on September 4, 2004. The Emergency Response Data Acquisition Display System (ERDADS) failed at 2:12 a.m., but was restarted and functioning correctly as of 3:40 a.m. The licensee also reported that the NRC link to Unit 1 had been reestablished, but the NRC link to Unit 2 had not been restored.
- EN #41021 on September 5, 2004. At approximately 11:50 p.m. on September 4, 2004, the Emergency Notification System (ENS) direct connection with the NRC was lost, as was the ERDADS link between Unit 1 and the NRC. By 12:20 a.m., the ENS connection had been recovered, but the ERDADS link to Unit 2 was still out of service from earlier in the day because of a failure of the modem for this circuit. Upon initial troubleshooting, it appeared that the Unit 1 modem had also failed. The ENS and ERDADS were in active use at the time of the loss for the Unusual Event condition resulting from the severe weather conditions associated with Hurricane Frances. The modems are serviced by NRC contractors, and repairs were to be pursued once weather conditions allowed access to the site.
- Update to EN #41006 on September 5, 2004. The licensee terminated the Unusual Event at 5:20 p.m.
- Update to EN #41018 on September 17, 2004. The licensee retracted this EN because continued operation and online troubleshooting would have been practical if the plant had not been required to shut down for the approaching hurricane. [This update is included for completeness.]

The NRC received the following ENs from St. Lucie for the period from September 24 through September 26, 2004, for Hurricane Jeanne:

- EN #41067, on September 24, 2004. The licensee declared an Unusual Event at 5:00 p.m. in response to a hurricane warning in effect.
- Update to EN #41067 on September 25, 2004. The licensee reported that Unit 1 began a shutdown at 8:20 a.m., and Unit 2 would begin plant shutdown at 9:00 a.m. in preparation for the hurricane. Both units were expected to be in hot shutdown by early afternoon. Winds at the site were projected to reach 120 mph.
- Update to EN #41067 on September 25, 2004. The licensee reported at 1:13 p.m. that both units were shut down and removed from service.
- EN #41072, on September 26, 2004. The licensee declared an Unusual Event attributable to a LOOP for both units. Offsite power was lost at 11:56 p.m. on September 25. All four EDGs started and properly loaded, and all systems operated as expected. Shutdown cooling was established on Unit 1 at 12:20 a.m. Efforts continued to place shutdown cooling in service on Unit 2.
- Update to EN #41072 on September 26, 2004. The licensee reported at 2:57 a.m. that during a control board walkdown, operators determined that the 1B intake cooling water pump had not automatically started as expected. The pump was subsequently started, and the cause of the failure would be investigated and corrected prior to restart.

- EN #41073 on September 26, 2004. The NRC Operations Center reported to the licensee that the Emergency Response Data System (ERDS) link had been lost at 7:09 p.m. on September 25, based upon the logged time of the last data update. The station was in constant communication with the Operations Center at the time because of the severe weather in the area associated with Hurricane Jeanne. The link was restored for both units at 11:44 p.m. on September 25 by performing the normal initiation procedure. It is suspected that the link was lost as a result of the weather conditions. The link was lost again at approximately 1:03 a.m. on September 26. The Unit 1 ERDS link was restored approximately 1 hour later, and troubleshooting of the Unit 2 link was in progress.
- Update to EN #41072 on September 26, 2004. The licensee reported at 10:50 a.m. that both units recovered offsite power and the site exited the LOOP Unusual Event.
- Update to EN #41067 on September 26, 2004. The licensee reported that at 2:13 p.m. that the hurricane warning had been discontinued and the Unusual Event exited.

The licensee submitted an LER (Ref. 16) on the September 25, 2004, dual unit LOOP event during Hurricane Jeanne. The LER provided some additional details and corrective actions, including the following statements:

- The LOOP was caused by two independent electrical faults associated with wind-driven salt contamination. Post-storm testing demonstrated that the switchyard insulation was clean, due to a self-cleaning phenomenon of the hurricane which was also observed in other substations.
- An additional cause of the LOOP is that the switchyard design requires removal of certain cross-ties when a unit is off-line. If the switchyard design had non-load interrupting disconnect switches in the main transformer lines, additional cross-ties would be provided when a unit is off-line. Such a design would be more robust during extreme environmental conditions. St. Lucie is considering this design modification. In this event, two outgoing transmission lines remained energized to the site.
- The 2A1 EDG fuel day tank solenoid valve failed to open, such that the fuel day tank level had to be manually controlled by local operation.
- The hurricane hampered the restoration of offsite power to the units' electrical buses. Safe shutdown loads remained connected to the EDGs even after power was capable of being restored because conditions would not allow personnel to safely inspect the switchyard. One of the offsite lines that could have been used to power the unit's electrical buses was restored 8 minutes after the LOOP. Offsite power was restored to Unit 1 and 2 electrical buses about 10 and 11 hours, respectively, after the LOOP.

The licensee submitted an LER (Ref. 17) on the Unit 2 reactor auxiliary building (RAB) missile shield doors not being closed, as discovered while preparing to restart following Hurricane Jeanne. Specifically, exterior doors on the east side RAB 62-foot elevation were found open. Subsequent investigation determined that the exterior doors were credited as missile shields. The apparent reason for this condition was attributed to lack of procedural guidance to ensure that the missile shield doors are kept closed during normal plant operations and severe weather conditions. The missile shield doors were closed, and future corrective actions include procedure changes and training. Open Unit 2 missile shields exposed safety-related equipment to tornado-induced missiles. The doors with the open missile shields provided access to the component cooling water surge tank room, and the heating and ventilation room.

The licensee's risk assessment for this condition concluded that the open missile shields had no adverse effect on the health and safety of the public.

Hurricane Preparations and Related Inspection Activities at St. Lucie

Reference 18 documents the resident inspectors' activities during this time period. The following paragraphs describe some of those inspection activities.

During the weeks of August 8, August 29, and September 19, 2004, the inspectors verified the status of licensee actions in accordance with the licensee's severe weather preparations procedure, as Hurricanes Charley, Frances, and Jeanne threatened the site. This verification included physical walkdowns of the licensee's property and discussions with responsible licensee personnel regarding systems, structures, and components vulnerable to high winds and potential flooding during a hurricane. The inspectors also specifically examined the state of preparation and readiness for hurricane conditions of the EDG rooms, ultimate heat sink, and switchyard.

The inspectors reviewed the licensee's overall preparations and protective actions prior to and during the onset of the extreme weather conditions associated with Hurricanes Frances and Jeanne. The inspectors toured protected areas and exterior plant grounds for loose debris and unsecured material, which could pose a hazard to important plant equipment during high winds. The inspectors continuously monitored control room activities, including the shutdown and cooldown of both units. The inspectors routinely attended the hurricane preparation status and progress meetings, and reviewed and discussed with management the provisions for staffing, relieving, and supplying plant operators, security guards, health physics, maintenance, and emergency response organization (ERO) personnel included in the station lockdown. The inspectors observed and participated with licensee ERO personnel in the Technical Support Center while they monitored storm conditions, unit status, and implemented necessary corrective actions and compensatory measures. In addition, the inspectors also observed and examined significant aspects of the licensee's planning and conduct of post-hurricane plant damage assessment and recovery, and reviewed condition reports generated by the licensee to verify that adverse weather related problems were being identified and resolved.

The inspectors performed inspection activities associated with external and internal flood protection. In particular, the inspectors reviewed multiple condition reports and associated corrective actions involving flooding that were generated and dispositioned within the past year. The inspectors also performed detailed walkdowns of the auxiliary feedwater pump areas, reviewed the applicable UFSAR report section for flooding, and reviewed requirements for beach dune and old beach road inspections. The inspectors also verified that specific areas met stated UFSAR requirements. Inspectors also walked down the RAB flooding procedure to ensure required actions could be accomplished as stated, and examined specific RAB equipment susceptible to flooding damage. In addition, the inspectors reviewed the sump level switch preventive maintenance schedule, as well as a sample work order used for switch calibration.

No findings of significance were identified.

2.3 Crystal River 3

Crystal River 3 is a Babcock and Wilcox PWR with a dry ambient containment located 7 miles northwest of Crystal River, Florida, on the Gulf of Mexico seacoast. From the Crystal River 3 final safety analysis report (FSAR), the once every 100 years extreme wind for the site is 110 mph at the 30-foot elevation, and Class I buildings are designed for 300-mph tornado winds. Also, from the Crystal River 3 FSAR, the calculated maximum storm tide level is at elevation 121.4 feet, with mean low water level at elevation 88.0 feet. For this 121.4-foot tide level and its associated wave action, local protection is provided to ensure the integrity of safety-related structures and systems from wave overtopping of the site's protective embankment. As previously stated, Hurricane Frances was a tropical storm with winds less than 74 mph when it impacted operation of the Crystal River site.

The NRC received the following ENs from Crystal River for the period from September 5 through September 8, 2004, for Hurricane Frances:

- EN #41022, on September 5, 2004. The licensee declared an Unusual Event at 5:10 p.m. in response to a hurricane warning in effect.
- EN #41023, on September 6, 2004. The licensee reported an automatic trip at 11:50 a.m. following a partial LOOP. The plant was stable on natural circulation, and the B EDG started as expected. The cause of the partial LOOP was under investigation.
- EN #41024, on September 8, 2004. The licensee reported identification of a potential pressure boundary leak while performing a plant walkdown. The potential leak was located on a weld associated with a pressurizer level sensing line. The licensee intended to cool down to Mode 5 and perform additional inspections and necessary repairs.
- EN #41027 on September 8, 2004. The licensee reported re-actuation of the B train of the emergency feedwater system. This actuation occurred while restoring a main feedwater pump to operation.
- Update to EN #41027 on September 8, 2004. The licensee retracted its previous event report.
- Update to EN #41022 on September 7, 2004. The licensee terminated the Unusual Event at 10:17 a.m. Offsite power had been restored and the hurricane warning lifted.
- EN #41081 on September 30, 2004. The licensee reported the B-train emergency feedwater actuation, which occurred on September 8. [This EN is included for completeness.]

The licensee submitted an LER (Ref. 19), which provided additional details on some aspects of the September 6, 2004, reactor trip and partial LOOP event. In the LER, the licensee stated that phase-to-ground faults occurred concurrently on a 230-kV transmission line and a 230-kV switchyard south bus breaker. The transmission line fault was caused by diameter loss and subsequent mechanical failure of a carbon steel pin in a vertical string of insulators as a result of high wind conditions. The diameter loss was caused by possible leakage current, which led to spark erosion and severe electrochemical corrosion of the carbon steel pin. The tripping of the 230-kV switchyard south bus was attributable to a flashover on Breaker 3232 as a result of contamination from wind and salt spray from the passing of Frances. Licensee corrective actions included replacing the failed vertical string of insulators, and inspecting

and replacing additional insulator strings. Breaker 3232 was evaluated, tested, and inspected. A complete hot-wash was performed on insulators and breakers on the 230-kV switchyard south bus prior to unit restart. A visual inspection of other sections of the 230-kV switchyard buses was also performed. The licensee also reported that the annunciator alarm system was overloaded as a result of multiple post-trip alarms. The system was reset, but approximately 20 minutes of event alarm data were lost. Finally, the licensee reported that the emergency lubricating oil pump motor for the 2B main feedwater pump turbine failed as a result of incorrectly terminated motor power leads.

Hurricane Preparations and Related Inspection Activities at Crystal River

Reference 20 documents the resident inspectors' activities during this time period. The following paragraphs describe some of those inspection activities.

On August 12 and 13, 2004, in preparation for Hurricane Charley (which was forecast to enter through the Tampa Bay/Crystal River area), the inspectors reviewed the licensee's implementation of hurricane preparations, using the licensee's violent weather procedure. In particular, the inspectors reviewed licensee activities to verify that they maintained the ability to protect vital systems and components from high winds and flooding associated with hurricanes. Additionally, the inspectors toured EDG building flood walls and doors, the berm area, instrument air compressors, and selected major electrical transformers to check for any observable vulnerabilities, such as inadequate sealing of water-tight penetrations, inoperable sump pumps, or degraded barriers. The inspectors verified that the licensee's Violent Weather Committee had been established and an initial preparatory walkdown had been completed. The inspectors also reviewed nuclear condition reports to verify that the licensee was identifying and correcting adverse weather protection issues, and they followed EDG testing to verify that the EDGs were in a state of readiness. As the storm approached, the inspectors monitored control room activities and attended the licensee's status briefings to verify that actions were consistent with violent weather planning. The inspectors remained onsite until the hurricane warning was downgraded.

On September 2–6, 2004, the inspectors observed the licensee's preparations for Hurricane Frances. Their activities were similar to those previously described for Hurricane Charley, except that they toured the intake structure and Intermediate Building instead of the instrument air compressors and selected major electrical transformers. The inspectors were in the control room and observed operator response to the reactor trip attributable to a partial LOOP on September 6. The inspectors also monitored the plant's recovery and return to power on September 11 and 12. On September 13–16, the inspectors reviewed the licensee's preparation for Hurricane Ivan, and noted that fuel and water inventories were checked to ensure that adequate supplies were available.

The inspectors performed inspection activities associated with external and internal flood protection. This review included the relevant FSAR section that depicted protection for areas containing safety-related equipment to identify areas that might be affected by internal flooding. The inspectors also conducted a walkdown of the internal areas of the turbine building and auxiliary building to ensure that flood protection measures were in accordance with design specifications. Similarly, the inspectors checked the licensee's flooding procedure to ensure that adequate measures were established to minimize the effects of turbine building flooding

attributable to rupture of a main condenser diaphragm. Specific attributes that were checked included structural integrity, sealing of penetrations below the design flood line, adequacy of water-tight doors between floor areas, and operability of sump systems. The inspectors also checked selected related work requests to verify that timely repairs were completed, and they reviewed relevant FSAR sections that depicted design flood levels and protection for areas containing safety-related equipment to identify areas that may be affected by external flooding. The inspectors also conducted a general site walkdown, with a specific walkdown of the external areas of the turbine building, auxiliary building, and berm to ensure that flood protection measures were in accordance with design specifications, and they checked the licensee's violent weather procedure to ensure that adequate measures were established to protect against external flooding attributable to hurricanes. Specific plant attributes that were checked included structural integrity, sealing of penetrations below the design flood line, and adequacy of water tight doors between flood areas. In addition, the inspectors checked a nonconformance report regarding flooding in an external cable vault to ensure that no leakage path existed through the plant flood barriers.

No findings of significance were identified.

3. AGENCY HURRICANE PREPARATIONS

The detailed hurricane preparations taken by the resident inspectors, and those inspectors assigned to assist the resident inspectors, were documented in inspection reports and discussed in Section 2 of this report. These preparations were of primary interest for this study. To provide a more complete understanding of agency preparations, this section briefly describes regional office hurricane preparations and response. Headquarters has a continuously staffed Operations Center to receive emergency notifications and inform NRC headquarters management, as appropriate, so that the appropriate agency response can be initiated. This report does not include a detailed discussion of headquarters emergency response.

Region II's hurricane response is formalized in a supplemental incident response procedure. This procedure is very detailed. Some important components of the plan are provisions for (1) hurricane tracking; (2) NRC onsite presence during the event; (3) augmentation of the resident inspector staff, including logistics for making travel arrangements; (4) activation and long-term staffing of the regional incident response center; (5) emergency kits, equipment, and transportation vehicles; (6) communications and communications equipment (including cell phones, ERDS, pagers, satellite phones, etc.); and (7) public affairs and State liaison support. The procedure also contains provisions for conducting lessons learned so that response can be continually improved. Many agency lessons learned were identified and assigned as a result of exercises and the 2004 hurricane season. The lessons learned document is not publicly available.

Another key component of Region II's hurricane response procedure is the inclusion of site-specific hurricane matrices. These matrices include emergency action levels, Technical Specification requirements, shutdown requirements, and applicable licensee operating procedures. Region II has designated primary and secondary hurricane sites. Each resident inspector office at primary hurricane sites has been outfitted with standardized emergency equipment and supplies, including enhanced communications equipment, and secondary sites also have some enhanced communications equipment. Finally, Region II incident response staff provide training before or early in the hurricane season to all regional staff members who may be involved in responding to hurricanes.

Region II has provided its hurricane procedure to many of its stakeholders in order to improve communications with them and to ensure that our planned preparations and response are known and understood. Region II stated that the level of detail and thought in its hurricane procedure is a direct outgrowth of lessons learned in responding to exercises and real events (in particular, Hurricane Andrew in 1992). Region II has also shared its hurricane procedure with the other regions and headquarters in an effort to support their similar activities, and to standardize agency preparations and response to hurricanes and other natural disasters. All of these efforts directly contribute to licensee and staff preparedness for responding to hurricanes, and undoubtedly contributed to limiting the impact of the 2004 "Florida" hurricanes.

4. SUMMARY

The 2004 hurricane season was unprecedented, in that 4 of the 10 costliest hurricanes in U.S. history all struck within a 7-week period, and each had a major impact on Florida. Two of the hurricanes (Frances and Jeanne) made landfall at virtually the identical location and followed similar tracks across central Florida.

Some overall observations can be made from a detailed review of the 2004 "Florida" hurricanes:

- Although the hurricanes disrupted the operation of the impacted NPPs, they did not have a significant impact on nuclear safety.
- Hurricane preparations by the NRC and its licensees appeared to be effective.
- NPPs are robust facilities, which are designed to withstand the impact of severe weather, such as hurricanes. The three main factors that limited the safety impact of hurricanes were the plants' robust design, successful operation of EDGs during the events, and the limited extent or duration of the associated LOOPs. Although not quantifiable, licensee and NRC hurricane preparations, undoubtedly, also contributed to the limiting the safety impact of the hurricanes.
- The reportable impacts on the NPPs were mainly confined to the three areas of complete or partial LOOP, loss of sirens, and loss of communications equipment. Of these, LOOP is the most risk significant, although loss of sirens or communications equipment could hinder emergency response to an event. The site preparations and the hurricane impacts including the equipment affected, contributing causes, and licensee corrective actions may all provide useful insights for other plant sites in preparing for future hurricanes or other severe weather conditions.
- All three sites discussed in this report experienced a LOOP or partial LOOP. These events had some commonalities in their contributing causes:
  - < Undetected degraded transmission line insulators at Brunswick and Crystal River, which failed during the storm conditions.
  - < Switchyard designs or configurations which could be enhanced, at Brunswick and St. Lucie, to be more robust for extreme weather conditions.
  - < Breaker faults or failures related to salt contamination or moisture intrusion at all three sites. At one site, the licensee stated that preventive and corrective maintenance activities had not identified moisture buildup as a condition requiring corrective action.
- In terms of loss of sirens and communications, Brunswick reported a peak loss of 25 of 36 sirens as a result of a loss of power. Note that licensees have alternative provisions for public notification when sirens are inoperable. St. Lucie also experienced an ERDADS or ERDS loss during Hurricanes Frances and Jeanne, and a loss of the ENS during Hurricane Frances.
- Region II commented and provided some site access and security insights on the 2004 "Florida" hurricanes. One insight was that site access during hurricanes (i.e., the ability get needed equipment and licensee and NRC staff to and from the site) is as important as the communications and siren issues discussed in the report. Security considerations also have a significant impact, with much interaction with the licensee. Note that the report

contains only a very limited discussion of such matters, in order to keep the report nonsensitive.

- In addition to the equipment problems described above, all three plants experienced unexpected equipment malfunctions or failures during their events. Brunswick had failures of the B-train standby gas treatment system and failure of some load shedding for EDG-1 as a result of a mispositioned, previously modified, relay dust cover. St. Lucie experienced problems with a feedwater regulating valve, SBCS, and a breaker for an intake cooling water pump. Crystal River had an overloaded annunciator alarm system and failure of an emergency lube oil pump for a main feedwater pump turbine.
- Despite the overall effective hurricane preparations by the NRC and its licensees, St. Lucie subsequently found and reported that RAB missile shield doors were open, potentially exposing safety-related equipment to tornado-induced missiles. The licensee stated that the doors could have been open for several years.

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APPENDIX

THE SAFFIR-SIMPSON HURRICANE SCALE

APPENDIX

THE SAFFIR-SIMPSON HURRICANE SCALE

The Saffir-Simpson Hurricane Scale is a 1–5 rating based on the hurricane's **present intensity** [emphasis added]. This is used to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. **Wind speed is the determining factor** [emphasis added] in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Note that all winds are using the U.S. 1-minute average. This information is from the National Hurricane Center Web site, available at http://www.nhc.noaa.gov/aboutsshs.shtml.

Category One Hurricane:

Winds 74–95 mph (64–82 kt or 119–153 km/hr). Storm surge generally 4–5 feet above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.

Category Two Hurricane:

Winds 96–110 mph (83–95 kt or 154–177 km/hr). Storm surge generally 6–8 feet above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2–4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings.

Category Three Hurricane:

Winds 111–130 mph (96–113 kt or 178–209 km/hr). Storm surge generally 9–12 feet above normal. Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Damage to shrubbery and trees with foliage blown off trees and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3–5 hours before arrival of the center of the hurricane. Flooding near the coast destroys smaller structures with larger structures damaged by battering from floating debris. Terrain continuously lower than 5 feet above mean sea level may be flooded inland 8 miles (13 km) or more. Evacuation of low-lying residences within several blocks of the shoreline may be required.

Category Four Hurricane:

Winds 131–155 mph (114–135 kt or 210–249 km/hr). Storm surge generally 13–18 feet above normal. More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3–5 hours before arrival of the center of the hurricane. Major damage to lower floors of structures near the shore. Terrain lower than 10 feet above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 miles (10 km).

Category Five Hurricane:

Winds greater than 155 mph (135 kt or 249 km/hr). Storm surge generally greater than 18 feet above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3–5 hours before arrival of the center of the hurricane. Major damage to lower floors of all structures located less than 15 feet above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5–10 miles (8–16 km) of the shoreline may be required.