November 16, 2000

MEMORANDUM TO: Samuel J. Collins, Director
Office of Nuclear Reactor Regulation

William F. Kane, Director
Office of Nuclear Material Safety and Safeguards

FROM: Ashok C. Thadani, Director **/RA/ Ashok C. Thadani**
Office of Nuclear Regulatory Research

SUBJECT: TRANSMITTAL OF RESEARCH INFORMATION LETTER RIL-0001 "PROBABILISTIC STORM SURGE ELEVATIONS FOR THE ATLANTIC AND GULF COASTS"

Attached is the subject Research Information Letter, which describes results of recent research in storm surge levels induced by hurricanes on the Atlantic and Gulf coasts of the United States. The study was based on probabilistic and statistical methodology that is more advanced than previous models of hurricane storm surges. Results confirm that the design flood levels of plants in that region are adequate.

Recent flooding at the Blayais plant in France has brought the question of coastal flooding into renewed focus. The French nuclear agency (DSIN) has ordered that dikes that were raised in the 80s be raised again and that the heights needed to be recalculated. In order to make use of new hurricane data in the U.S. and improving the methodology, we have budgeted for anticipatory research in FY2002 to update the hurricane data base and determine the need to revise the methodology used to calculate storm surge levels.

Attachment: As stated

cc: W. Travers
C. Paperiello
F. Miraglia

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RESEARCH INFORMATION LETTER RIL-0001

PROBABILISTIC STORM SURGE ELEVATIONS FOR THE ATLANTIC AND GULF COASTS

Background

Several nuclear power plants are located on the Atlantic and Gulf coasts and could be affected by hurricane-induced storm surges. Regulatory Guide 1.59 (Reference 1) lists methods acceptable to the NRC for estimating probable maximum water levels of design basis floods for nuclear power plants. Appendix C of the Reg. Guide describes simplified methods of estimating probable maximum surges on the Atlantic and Gulf coasts. The calculations are done using tables and graphs in the appendix that are based on probable maximum flood levels developed by the U.S. Army Corps of Engineers.

According to the Reg. Guide, a probable maximum hurricane is to be considered in order to determine the probable maximum water level at seashores. This does not include effects of wind-generated wave activity, which has to be added to define the upper limit of the flood potential. In the case of a hurricane, the winds generated by the storm are to be used to determine wave heights. The probable maximum hurricane is a hypothetical storm whose induced flood levels are expected to occur once every 2000 years.

Appendix C of Reg. Guide 1.59 lists procedures that permit calculating probable maximum water levels in several steps. First, a probable maximum surge is determined from tables. This is a stillwater level based on probable maximum hurricane data from the National Oceanic and Atmospheric Administration (NOAA). An ocean bed profile to 600 feet (180 m) depth at the given location is to be used for comparison with the tables in Appendix C. Second, it is assumed that the peak probable maximum surge coincides with a 10% exceedance high spring tide plus initial rise (an anomalous departure from the predicted tide). Third, wind-wave effects are to be calculated according to the Shore Protection Manual (Reference 2). Fourth, up to this point open coast conditions have been assumed; therefore, the effects induced by barrier islands, inlets, etc. are to be evaluated next, using the same manual.

A NOAA study published in 1992 (Reference 3) used a different methodology and found surge elevations which, in the case of the Brunswick nuclear plant in North Carolina, exceeded the design basis flood level by 6.4 feet (2 m). These results cast doubt on the adequacy of the design basis for the Atlantic coast nuclear power plants and of the NRC regulations used to determine the design basis. Consequently, the Brunswick plant had an independent assessment made of the NOAA report, including a new set of calculations, to verify that the design basis flood level provides adequate safety for the plant.

In response to a user need request (Reference 4), RES then contracted with the U.S. Army Corps of Engineers to derive realistic water level frequency relationships for the Brunswick plant using state-of-the-art techniques of modeling and statistical analysis. The new analyses were then compared with the hurricane induced surge elevations resulting from the NOAA and Brunswick studies. Later, the study was extended to include four more coastal nuclear plants, namely Crystal River, Turkey Point and St. Lucie, all in Florida; and Oyster Creek in New Jersey. Results of that investigation are described in an Army Corps of Engineers report (Reference 5).

Research Summary

The Coastal and Hydraulics Laboratory (CHL) at the Engineer Research and Development Center of the U.S. Army Corps of Engineers performed hurricane stage-frequency analyses for the five plants using a statistical technique named the empirical simulation technique (EST). The EST uses a bootstrap approach as described in References 6 and 7. This approach takes historical data consisting of storms and their storm parameters plus the response vector (the storm surge) and builds up a larger database by introducing small perturbations to the parameters. The EST also uses statistical resampling and nearest neighbor, random walk interpolation. In this procedure, hurricanes from a data set are selected randomly. One of the hurricane parameters (e.g. wind speed) is selected and the three hurricanes with the closest values are determined for use in interpolation. The same procedure is then applied to other hurricane parameters. Historical data are used to develop joint probability relationships among the various measured storm parameters. No simplifying assumptions are used so that the interdependence of parameters is preserved. The only assumption used is that future events will be statistically similar to past events in magnitude and frequency.

From a historical data set, the CHL selected a subset of storm events, called a “training” set, that is representative of the entire set of historical storms. The training set eliminates events that are nearly identical, which would produce the same response. However, it may also include historical storms with a perturbation, such as a different path. With the training set and the historical data set, stage-frequency relationships can be generated that are based on the whole historical data set without having to simulate all storms in the set. Random perturbations may result in more intense storms than the historical events, so that a future hurricane may be the storm of record. The EST produces N simulations of a T-year sequence of hurricane events based on the assumption stated above.

The modeling calculations use hurricane input parameters that include central pressure deficit, maximum winds, radius to maximum winds, distance from the eye of the storm to the location of interest, forward speed of the eye, and tidal phase. Wind and atmospheric pressure fields are then generated with a tropical wind field model. Next, peak storm surge elevations are derived from the wind model output using a finite element hydrodynamic model. A third step consists of estimating wave setup through a spectral wind wave model. Finally, after calculation of these variables through the different models, statistical techniques are used to develop frequency of occurrence relationships.

Various output parameters can be derived from this, the maximum total water surface elevation being the parameter of interest for the investigations described here. This includes the combination of storm surge, wave setup, and tide. Relationships between input and output parameters are highly nonlinear, involving conditions such as shoreline slope and temperature, among others.

Results derived from this new study using EST were then compared to the original design basis calculations for the five nuclear power plants, which were made using Reg. Guide 1.59, and to the additional study done by the Brunswick plant. Results were also compared with the 1992 NOAA study that applies only to the area of the Brunswick nuclear plant, and discrepancies were analyzed in terms of the assumptions and procedures used for these different modeling approaches.

Research Results

The two units of the Brunswick nuclear plant were licensed in 1974 and 1976 with a design basis flood level of 22 feet (6.7 m) derived from Reg. Guide 1.59 procedures. These procedures employ a bathystrophic storm surge theory to derive surge elevations induced by the probable maximum hurricane. The theory permits calculating surge levels along an ocean bottom transect. It is a 1-d method that cannot be applied to irregular shorelines involving inlets, barrier islands, etc. The method is considered obsolete today, but it was an accepted procedure at the time.

The new calculations commissioned by the Brunswick plant after the NOAA report was issued also employed probable maximum hurricane criteria. The NRC-commissioned study by the CHL serves, among other things, to ascertain that the design levels for Brunswick derived by the two studies (design and re-evaluation) provide adequate safety for the plant. The original design study used the quasi-empirical standard project hurricane model to define wind and pressure fields generated by the parameterized probable maximum hurricane. On the other hand, the wind field model used currently by the CHL is based on principles of physics and requires only eye location and central pressure as input. CHL's hurricane model is therefore not completely compatible with the standard project hurricane model. However, wind and atmospheric pressure fields consistent with the standard project hurricane were approximated and used as input for the subsequent modeling.

Hurricane Hazel was selected for approximating the standard project hurricane because it was similar in trajectory and speed to the hypothetical storm. Hazel, which occurred in October 1954, was the storm of record for the study area. Hazel's central pressure was modified to generate a probable maximum hurricane-like storm event for the wind field model. Its landfall position was also changed to impose a critical path that produced the greatest surge at the study site. Surge levels computed with this input were then compared with the design basis flood levels for the Brunswick nuclear plant to determine if its safety margins are adequate.

While the results of the two earlier Brunswick studies are very similar, the EST analysis predicted a total surge elevation (including storm surge, wave setup, and tide) of 16 to 17 feet (4.9 to 5.2 m) MSL for a 2000 year return period. This elevation is 5 to 6 feet (1.5 to 1.8 m) lower than the 22 feet (6.7 m) design basis for the plant, which was computed using the probable maximum hurricane. The probable maximum hurricane is also estimated for a return period of 2000 years.

In the case of the other four plants (Turkey Point, St. Lucie, Crystal River, and Oyster Creek), the EST derived levels were lower than the design levels by 1 foot (0.3 m), 7.8 feet (2.4 m), 26.5 feet (8.1 m), and 12.1 feet (3.7 m), respectively.

The 1992 NOAA study used the joint probability method for statistical analysis and predicted a storm surge elevation of 28.4 feet (8.7 m), or 6.4 feet (2 m) above the design level. NOAA also used the SLOSH model (developed in the 1960s and 1970s) for their storm surge calculations. This is a 2-d finite-difference model to solve the mass conservation and Navier-Stokes equations. The joint probability method was used to synthesize a set of hypothetical storms and derive storm parameters. A probability density function was then calculated for each parameter with the assumption that storm parameters are independent.

The surge elevation of 28.4 feet calculated by NOAA for the Brunswick site was based on a combination of parameters consistent with an extreme hurricane. However, this storm may not be realistic, because the parameters were assumed to be independent, and because the combination of parameters used may be unrealistic. In addition, certain roads in the vicinity of the site may not have been included in the SLOSH calculations. In particular, highways 211, 87, and 133 could act as levees along the storm path chosen, thus impeding storm surge propagation. It could not be determined whether the highways were included in the model, because NOAA refused to release its model. It was found, however, that the model showed considerable surge beyond the highways, suggesting that they may not have been properly represented in the model.

Because the EST estimates are based on prototype data, they should be more realistic than the hypothetical events used in NOAA's joint probability method. The Brunswick plant design elevation of 22 feet has a return period of about 100,000 years according to the EST analysis. The EST produced a 100-year total surge elevation of about 11 to 12 feet (3.4 to 3.7 m) at three stations near the Brunswick nuclear plant. This result is consistent with historical data, thus confirming the validity of the EST method.

Regulatory Implications

Present NRC regulatory guidance is based on a methodology that has been shown to provide adequate safety margins. The study performed by the Coastal Hydraulics Laboratory of the U.S. Army Corps of Engineers has shown that the design basis flood levels for the five nuclear plants investigated ensure adequate safety margins against extreme hurricane-induced storm surge flooding. However, the study has also shown that the previous studies resulted in frequencies associated with given storm surge elevations that are overly conservative. The EST study produced lower frequencies, or lower surge elevations for a certain return period. Results of the design calculations and the review study for the Brunswick plant were very similar and higher than the EST results. For all five plants, the EST results for 2000 year recurrence are lower than the design flood levels.

The NOAA study results are inconsistent with the three other sets of data and provide storm surge levels that are overly conservative. This discrepancy is probably due to the fact that the hypothetical storms used in the study are based on the joint probability method and do not realistically replicate the historic storms in the study region. Although the synthesized storms may be similar to historic ones, their probability of occurrence seems to be greater. Thus, the methodology used by NOAA predicts more intense storms that may occur more frequently, leading to an overestimation of storm surges.

Closure

Analysis of hurricane storm surge levels for five plants on the Atlantic and Gulf coasts has shown that the design basis flood levels of these plants are adequate. Related safety issues can therefore be closed. With respect to the Brunswick nuclear plant, the safety issue was closed by NRR in 1998 (Reference 8). However, the new storm surge methodology developed by the U.S. Army Corps of Engineers leads to different and often appreciably lower surge levels. Therefore, the existing regulatory guidance should be revised for use by new applicants. Revised guidance would incorporate new hurricane data and methodologies for determining design basis flood levels at locations on the Gulf or Atlantic coasts. We propose to initiate a research contract to provide the basis for a revised Regulatory Guide.

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