2.4.4 POTENTIAL DAM FAILURES

REVIEW RESPONSIBILITIES

Primary - Mechanical and Civil Engineering Branch (EMEB)

Secondary - None

I. AREAS OF REVIEW

In this section of the site safety assessment for an early site permit (ESP) application, the hydrogeologic design basis is developed to ensure consideration of any potential hazard to the safety-related facilities of a nuclear power plant or plants of specified type (or falling within a plant parameter envelope [PPE]) that might be constructed on the proposed site due to the failure of upstream and downstream water control structures. The areas of review include consideration of flood waves (bores) from severe breaching of upstream dams and the potential loss of water supply due to failure of a downstream dam, domino-type failures of dams, landslides, and effects of sediment deposition and erosion.

When data are provided to show that seismic events will not cause failures of upstream dams that could produce the governing flood at a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site, this section may contain additional data and other information to support a contention that the dams are equivalent to seismic Category I structures and will survive a local equivalent of the safe shutdown earthquake (SSE) ground motion coincident with a 25-year flood or will survive ½ of the SSE gound motion coincident with a standard project flood (SPF).[1] In such cases, the EMEB will evaluate the data necessary to justify such a classification. EMEB review procedures are outlined in the appropriate geosciences and structural sections of this review standard. The balance of this section applies to the hydrologic analyses of dam failures or breaches.

Where analyses are provided in support of either a conclusion that a probable maximum flood (PMF) should be the design basis flood for a stream, or that a postulated or arbitrarily assumed dam failure flood is the design basis flood for a stream, the areas of review consist of the following:

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[1] This combination is based on the guidance of Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants" and past NRC licensing practice. Regulatory Guide 1.59 references ANSI Standard N170-1976, which has been superseded by ANSI/ANS-2.8-1992, "American National Standard for Determining Design Basis Flooding at Power Reactor Sites." Section 9.2.1.2 of this standard calls for consideration of dam failure caused by the Operating Basis Earthquake (OBE) coincident with the peak of flood. Existing reactors were licensed using an OBE equal to ½ the SSE. Though a 1997 rulemaking eliminated use of the OBE in reactor design, the value of ½ the SSE (or other value if justified by an ESP applicant) may be used to analyze seismically induced dam failures.

1. Conservatism of modes of assumed dam failure and deposition of debris downstream.

2. Consideration of flood control reservoirs at full pool level.

3. Conservatism of coincident flow rates and levels, depending on whether failure is postulated with an equivalent SSE coincident with a 25-year flood or ½ of the SSE coincident with an SPF. An SPF is considered to be about forty percent of a PMF.

4. Flood wave attenuation to downstream dams or to the site, whichever would be encountered first.

5. Potential for multiple dam failures; flood wave effects and potential for failure of downstream dams.

6. Hydraulic failure as a result of overtopping for any reason.

7. Dynamic effects of possible bores on exposed facilities of a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site.

8. Conservative flow conditions for downstream dam failures that can influence safety-related water supplies.

9. Applicability and conservatism of models used to predict the effects of dam failure floods including breach shape and rate of failure.

II. ACCEPTANCE CRITERIA

Acceptance criteria for this section of this review standard are based on meeting the requirements of the following regulations:

1. 10 CFR Parts 52 and 100 (Refs. 1 and 2) as they relate to evaluating hydrologic features of the site.

2. 10 CFR 100.23 as it relates to establishing the design basis flood due to seismic dam failure.

The regulations at 10 CFR 52.17(a) and 10 CFR Part 100.20(c) require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability to host a nuclear reactor or reactors.

The regulations at 10 CFR Parts 52 and 100 are applicable to safety assessment Section 2.4.4 because it addresses the physical characteristics, including hydrology, considered by the Commission when determining the acceptability of a site for a power reactor. To satisfy the hydrologic requirements of 10 CFR Parts 52 and 100, the applicant's safety assessment should contain a description of the hydrologic characteristics of the region and an analysis of potential dam failures. The description should be sufficient to assess the acceptability of the site and the potential for those characteristics to influence the design of structures, systems, and components important to safety. Meeting this criterion provides reasonable assurance that effects of high water levels resulting from failure of upstream dams, as well as those of low

water levels resulting from failure of a downstream dam, would pose no undue risk to the type of facility proposed for the site.

For those cases where a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of parameters. Important PPE parameters for safety assessment Section 2.4 include but are not limited to precipitation (e.g., maximum design rainfall rate and snow load) and the allowable site water level (e.g., maximum allowable flood or tsunami surge level and maximum allowable ground water level).

The regulation at 10 CFR 100.23 requires consideration of geologic and seismic factors in determination of site suitability. Section 100.23(c) requires an investigation to obtain geologic and seismic data for evaluating seismically induced floods, including failure of an upstream dam during an earthquake.

The regulation at 10 CFR 100.23 is applicable to Section 2.4.4 of this review standard because it requires investigation of seismically induced floods or low water levels that guide the Commission in its consideration of the suitability of proposed sites for nuclear power plants. More detailed guidance on the investigation of seismically induced floods is provided in Regulatory Guide 1.70 (Ref. 3), including results for seismically induced dam failures and antecedent flood flows coincident with the flood peak. Meeting 10 CFR 100.23 provides reasonable assurance that, given the geologic and seismic characteristics of the proposed site, a nuclear power plant or plants of specified type (or falling within a PPE) could be constructed and operated on the proposed site without undue risk to the health and safety of the public with respect to those characteristics.

Note: Though not required at the ESP stage, the applicant for a combined license (COL) will need to demonstrate compliance with General Design Criterion 2 (Ref. 4) as it relates to structures, systems, and components important to safety being designed to withstand floods.

To meet the requirements of 10 CFR Parts 52 and 100, and 10 CFR 100.23, as they relate to dam failures, the following specific criteria are used:

The staff will review the applicant’s analyses and independently assess the coincident river flows at the site and at the dams being analyzed. ANSI/ANS-2.8-1992 (Ref. 5) provides guidance on acceptable river flow conditions to be assumed coincident with the dam failure event. The applicant’s estimates (which may include landslide-induced failures) of the flood discharge resulting from the coincident events should be no more than 5% less conservative than the staff’s estimates to be acceptable. If the applicant’s estimates differ by more than 5%, the applicant should fully document and justify its estimates or accept the staff’s estimates.

For safety assessment Section 2.4.4.1 (Dam Failure Permutations): The location of dams and potentially "likely" or severe modes of failure should be identified. Dams or embankments for the purpose of impounding water for a nuclear power plant or plants that might be constructed on the proposed site should also be identified. The potential for multiple, seismically induced dam failures and the domino failure of a series of dams should be discussed. Approved models of the Corps of Engineers and the Tennessee Valley Authority are used to predict the downstream water levels resulting from a dam breach (Refs. 6 through 10). First-time use of other models will necessitate complete model description and documentation. Acceptance of the model (and subsequent analyses) is based on the staff review of model theory, available

verification, and application. Where other than instantaneous failure is assumed, the conservatism of the rate of failure and shape of the breach should be well documented. A determination of the peak flow rate and water level at the site for the worst possible combination of dam failures and a summary analysis (that substantiates the condition as the critical permutation) should be presented, along with a description (and the bases) of all coefficients and methods used. Also, the effects of other concurrent events on plant safety, such as blockage of the river and water-borne missiles, should be considered.

For safety assessment Sections 2.4.4.2 (Unsteady Flow Analysis of Potential Dam Failures) and 2.4.4.3 (Water Level at Plant Site): The effects of coincident and antecedent flood flows (or low flows for downstream structures) on initial pool levels should be considered. Use of the methods given in References 11 or 12 is acceptable for determination of initial pool levels. Depending upon estimated failure modes and the elevation difference between plant grade and normal river levels, it may be acceptable to use conservative simplified procedures to estimate flood levels at the site. Where calculated flood levels using simplified methods are at or above plant grade and using assumptions which cannot be demonstrated as conservative, it will be necessary to use unsteady flow methods to develop flood levels at the site. References 7, 13, and 14 are acceptable methods; however, other programs would be acceptable with proper documentation and justification. Computations, coefficients, and methods used to establish the water level at the site for the most critical dam failures should be summarized. Coincident wind-generated wave activity should be considered in a manner similar to that discussed in Section 2.4.3 of this review standard.

Appropriate sections of the guides described below are used by the staff to determine the acceptability of the applicant's data and analyses. Regulatory Guide 1.59[2] (Ref. 15) provides guidance for estimating the design basis for flooding considering the worst single phenomenon and combination of less severe phenomena.

III. REVIEW PROCEDURES

The conservatism of the applicant's estimates of flood potential and low water levels from structure failures is judged against the criteria indicated in subsection II above. An analysis is performed using simplified, conservative procedures (such as instantaneous failure, coincident SPF flows, minimal flood wave attenuation, and extrapolated site discharge-rating curves). Techniques for such analyses are identified in standard hydraulic design references and text books, such as those listed in the reference section (Refs. 16 through 31). If no potential flood problem exists, the staff safety evaluation report (SER) input is written accordingly. If the simplified analysis indicates a potential flooding problem, the analysis is repeated using a more refined technique which may include time rate of failure and hydrometeorologically compatible storm centering. Detailed failure models, such as those of the Corps of Engineers and the Tennessee Valley Authority, are utilized to identify the outflows from various failure modes. Models of the Corps of Engineers or the Tennessee Valley Authority are used to identify the outflow characteristics and resultant water level at the site (Refs. 6 through 10, and 13). The staff will develop a position based on the analyses performed; resolve, if possible, differences between the applicant's and staff's estimates; and write the SER input accordingly.

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[2] In using Regulatory Guide 1.59, references to ANSI N170-1976 should be read as references to ANSI/ANS-2.8-1992, which has superseded the earlier document.

The above reviews are performed only when applicable to the site or site region. Some items of review may be done on a generic basis.

IV. EVALUATION FINDINGS

For ESP reviews, the findings will summarize the applicant and staff evaluations in compliance with 10 CFR Parts 52 and 100, and 10 CFR 100.23, of the design basis maximum and minimum water levels caused by potential dam failures. If the applicant's estimates are within acceptable margins (described in subsection II), staff concurrence in the applicant's estimates will be stated. If the applicant's estimates are not within acceptable margins, and if a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site may be adversely affected, a position on use of the staff bases will be stated. If no dam failure review was undertaken at the ESP stage (of the scope described), this fact will be indicated. Evaluation of a dam constructed after issuance of an ESP would need to be performed at the COL stage.

Sample statements for ESP reviews follow:

> As set forth above, the distance (more than 480 km [300 mi]) to upstream reservoirs of appreciable size is such that the staff assessment leads to the conclusion that their arbitrarily assumed failure, under postulated combinations of floods and earthquakes of the severity discussed in Regulatory Guide 1.59, would not constitute a threat to a nuclear power plant of specified type [or to a facility falling within the plant parameter envelope submitted by the applicant] that might be constructed on the proposed site.
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> Dam failure-caused "worst case" floods were evaluated by the applicant based upon failures with consideration of only the location and sizes of upstream impoundments, and not on inherent capability of such structures to resist earthquakes, volcanic activity, and severe landslide-induced floods. The most severe flood of this kind was estimated based upon an assumed catastrophic failure of Dam A some 680 km (420 mi) upstream. The peak flow at the site from such a flood was estimated to be 85,000 m^3/s (3,000,000 cfs). This flow is estimated to occur about 2 days after the dam failure and reach elevation 12 m (39 ft) MSL, 3 m (10 ft) below plant grade.
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> A volcanically induced flood was assumed to cause a domino-type failure of the three dams on the tributary B River from a volcanic eruption of Mt. D. The evaluation indicated such an event could cause the second most severe artificial flood that would reach the site. This event was estimated to produce a peak flow at the site of 80,000 m^3/s (2,800,000 cfs) and a water level of 12 m (39 ft) MSL, 3 m (10 ft) below plant grade.
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> Therefore, the staff concludes that the plant design flood elevation, at plant grade of 15 m (50 ft) above mean sea level (MSL), is acceptable and meets the requirements of 10 CFR Parts 52 and 100, and 10 CFR 100.23 with respect to potential hazards due to dam failure floods.

The findings will address the envelope of site-related hydrologic parameters. These parameters should be representative of the most severe hydrologic characteristics likely to occur as a result of dam failure.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this section of this review standard.

This section will be used by the staff when performing safety evaluations of ESP applications submitted by applicants pursuant to 10 CFR Part 52. Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

VI. REFERENCES

1. 10 CFR Part 52, "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants."

2. 10 CFR Part 100, "Reactor Site Criteria."

3. Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants."

4. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

5. ANSI/ANS-2.8-1992, "Determining Design Basis Flooding at Power Reactor Sites."

6. "Routing of Floods Through River Channels," EM 1110-2-1408, Corps of Engineers, March 1960.

7. J. M. Garrison, J. P. Granju, and J. T. Price, "Unsteady Flow Simulation in Rivers and Reservoirs," Jour. Hydraulics Division, Proc. Am. Soc. of Civil Engineers, Vol. 95, No. HY5, pp. 1559-1576 (1969).

8. W. A. Thomas, "A Method for Analyzing Effects of Dam Failures in Design Studies," Corps of Engineers Hydrologic Engineering Center, Davis California (for presentation at the ASCE Hydraulics Division Specialty Conference, Cornell University, August 1972).

9. "Flow Through a Breached Dam," Military Hydrology Bulletin No. 9, Corps of Engineers (1957).

10. "Floods Resulting From Suddenly Breached Dams, Conditions of High Resistance," Misc. Paper No. 2-374, Report 2, Corps of Engineers (1961).

11. "Flood Hydrograph Package," HEC-1, Corps of Engineers Hydrologic Engineering Center, Davis, California, June 1998.

12. "Simulation of Flood Control and Conservation Systems," HEC-5, Corps of Engineers Hydrologic Engineering Center, Davis, California, October 1998.

13. "Gradually Varied Unsteady Flow Profiles," 723-62-L2450, Corps of Engineers Hydrologic Engineering Center, Davis, California, March 1969.

14. R. A. Baltzer and C. Lai, "Computer Simulation of Unsteady Flows in Waterways," Hydraulics Division, Proc. Am. Soc. of Civil Engineers, Vol. 94, No. HY4, pp. 1083-1117 (1968).

15. Regulatory Guide 1.59, "Flood Design Basis for Nuclear Power Plants."

16. Hunter Rouse, ed., "Engineering Hydraulics," John Wiley & Sons, Inc., New York (1950).

17. Ven Te Chow, ed., "Handbook of Applied Hydrology," McGraw-Hill Book Co., New York (1964).

18. J. J. Stoker, "Numerical Solution of Flood Prediction and River Regulation Problems," Reports I and II, New York Univ. (1953-54).

19. V. L. Streeter and E. B. Wylie, "Hydraulic Transients," McGraw Hill Book Co., New York, pp. 239-259 (1967).

20. Bureau of Reclamation, "Flood Routing," Chapter 6/0 in "Flood Hydrology,"Part 6 in “Water Studies," Volume IV, U.S. Department of the Interior (1947).

21. National Research Council (NRC), Safety of Dams : Flood and Earthquake Criteria, National Academy Press, Washington, D.C., 1985.

22. Dewey, R., and D. Gillette. 1993. “Prediction of Embankment Dam Breaching for Hazard Assessment.” Proc. Specialty Conference on Geotechnical Practice in Dam Rehabilitation,ASCE, 25-28 April 1993, Raleigh, North Carolina.

23. Froehlich, D. 1987. “Embankment-Dam Breach Parameters.” Proc. 1987 National Conference on Hydraulic Engineering, ASCE, 3-7 August 1987, Williamsburg, Virginia. pp. 570-575.

24. Froehlich, D. 1995. “Embankment Dam Breach Parameters Revisited.” Proc. Conference on Water Resources Engineering, ASCE, 14-18 August 1995, San Antonio, Texas.

25. MacDonald, T., and J. Langridge-Monopolis. 1984. “Breaching Characteristics of Dam Failures.” J. Hydraul. Eng. 110(5):567-586.

26. Von Thun, J. L., and D. Gillette. 1990. “Guidance on Breach Parameters.” U.S. Bureau of Reclamation, Denver, CO, 13 March 1990 (unpublished internal document). 17 pp.

27. U.S. Bureau of Reclamation, Training Aids for Dam Safety, Module: Evaluation of Hydrologic Adequacy, Technical Service Center, Denver, CO, 1990.

28. Committee on Safety Criteria for Dams, Safety of Dams - Flood and Earthquake Criteria, Prepared under the Auspices of Water Science and Technology Board, Commission on Engineering and Technical Systems, National Research Council, Washington, D.C., National Academy Press, 374 pp., 1985.

29. Cecilio, C. B. and A. G. Strassburger, Downstream Hydrograph from Dam Failure, Engineering Foundation Conference on Evaluation of Dam Safety, 1976.

30. Fread, D. L., DAMBRK - The NWS Dam-Break Flood Forecasting Model, National Weather Service, Silver Spring, Maryland, 1988 Version.

31. Westmore, Jonathan N. and Danny L. Fread, The NWS Simplified Dam-Break Flood Forecasting Model, National Weather Service, Silver Spring, Maryland, 1981.