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UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, DC 20555-0001

NRC INFORMATION NOTICE ~~2010~~2011-xx: ~~APPLICABILITY OF HISTORICAL~~ DAM FAILURE FREQUENCY ~~ESTIMATES~~UNDERESTIMATED IN PROBABILISTIC RISK ASSESSMENTS

ADDRESSEES

All holders of ~~an~~ operating ~~license or construction permit~~licensees for ~~a~~ nuclear power ~~reactor issued under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities,"~~reactors, except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

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~~All holders of or applicants for an early site permit, standard design certification, standard design approval, manufacturing license, or combined license issued under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."~~

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to alert addressees of a potentially non-conservative value for dam failure frequency ~~estimate used in external flooding analysis~~ that originated in 1980s reference documents ~~published in the 1980s~~ and was commonly adopted by ~~some~~ licensees in their probabilistic risk assessment (PRA~~)~~.

~~)~~ for external events. Using a non-conservative dam failure frequency may result in underestimating the risks to the plant associated with external flooding or loss of heat sink from the failure of upstream and~~/or~~ downstream dams or levees. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to correct any error resulting from ~~the use of~~ these reference documents. However, suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

~~**DESCRIPTION OF CIRCUMSTANCES**~~

BACKGROUND

The NRC staff recently ~~reviewed the use of~~ identified a potentially non-conservative value for dam failure frequency ~~estimates previously published in documents related to PRA for US nuclear power plants. Analysis performed in a PRA study (NSAC-1984)by~~contained in the

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Nuclear Safety Analysis Center (NSAC) ~~of the Electric Power Institute (EPRI) and participating utilities has been used by licensees performing external flooding analyses to evaluate vulnerabilities due to potential dam failure events. A subsequent~~ report ~~published by the US NRC on external event contributors to overall risk for the U.S. nuclear power plants, titled "NUREG/CR-5042, Evaluation of External Hazards to Nuclear Power Plants in the United States" also refers to the~~ NSAC/60 ~~study on the subject~~, "Oconee PRA a Probabilistic Risk Assessment of Oconee Unit 3." This dam failure frequency ~~estimates (USNRC, 1987).~~

value was commonly adopted by licensees in their PRA for external events. Published in 1984, NSAC/60 ~~provided an estimate for a dam~~ was prepared by NSAC in conjunction with Duke Power Company and provided their calculated value for the dam failure frequency of the Jocassee dam, a value commonly referenced by other licensees in their flooding analyses. The NSAC/60 PRA model determined the failure frequency ~~as part of the external flooding screening analysis. The framework used in NSAC/60 to develop this estimate was the compilation of historical~~for the Jocassee dam ~~failure events and operational years deemed applicable to specific dam characteristics considered in the study (a large, modern embankment dam).~~

~~Assumptions were made to screen out the applicable failure events which parsed the information available when the study was published by (i) dam composition, (ii) construction completion date, and (iii) failure modes. A~~by compiling data for similar types of dam failures, while taking into account a mathematical equation modeling that showed that more recently constructed dams displayed a ~~decrease in generic dam~~lower failure ~~rates with an increase in operational dam-years was assumed~~frequency, presumably due to ~~reflect~~ improvements ~~to methods of~~in dam design and construction. ~~A~~ NSAC/60 states that a Bayesian analysis using historical dam failures was ~~then~~ performed to estimate the annual failure frequency at the time the analysis was performed (1981) and associated uncertainty range for dams built within different time periods: 1900 – 1981, 1940 – 1981, and 1960 – 1981. The NSAC/60 PRA analysis determined the median annual failure frequencies ~~in NSAC/60 are in~~for the ~~range between 1.0~~Jocassee dam as 2.3 x 10^{-5}/year ~~and 2.5~~, 1.6 x 10^{-5}/year~~.~~, and 1.4 x 10^{-5}/year, respectively, from causes other than earthquakes and overtopping (which NSAC/60 states were considered in separate analyses.)

~~This study recognized~~The NSAC/60 approach estimated the failure frequency for the Jocassee dam by screening the available historical data for U.S. dams at the time of the analysis (1981) and using only the data deemed applicable to the Jocassee dam based on characteristics such as (i) dam composition, (ii) construction completion date, and (iii) failure modes. NSAC/60 describes the challenge in collecting sufficient historical information based on the scarcity of the data applicable to the specific dam characteristics considered, as well as the complexity of the actual phenomena controlling dam failures and its potential impacts to a nuclear power plant site. ~~Subsequently,~~

The NRC subsequently included the NSAC/60 dam failure frequency results in NUREG/CR -042, "Evaluation of External Hazards to Nuclear Power Plant in the United States" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML062260222), which was initially published in 1987. NUREG/CR-5042 reported bounding calculations with results of "10^{-6}/year or even smaller" for modern well-engineered dams and a

range of values between "10^{-4}/year and 10^{-5}/year," referring to NSAC/60 in both cases ~~(USNRC, 1987).~~.

DESCRIPTION OF CIRCUMSTANCES

~~BACKGROUND~~

~~Related NRC Communications~~

- ~~U.S. Nuclear Regulatory Commission, "Evaluation of External Hazards to Nuclear Power Plants in the United States," NUREG/CR-5042, Lawrence Livermore National Laboratory, December 1987, ADAMS Accession No. ML062260222.~~

~~Related External Databases~~

- ~~Stanford University, Department of Civil and Environmental Engineering, National Performance of Dams Program (http://npdp.stanford.edu/index.html).~~
- ~~US Army Corps of Engineers, National Inventory of Dams (http://nid.usace.army.mil)~~

~~Related non-NRC Communications~~

- ~~Nuclear Safety Analysis Center/Electric Power Research Institute, "NSAC-60 Oconee PRA: A Probabilistic Risk Assessment of Oconee Unit 3," Palo Alto, CA, 1984.~~
- ~~Baecher, G. B., M. E. Paté, and R. De Neufville (1980), "Risk of Dam Failure in Benefit-Cost Analysis," *Water Resource Research*, 16(3), 449–456.~~
- ~~Martz, H.F., and M.C. Bryson (1982), "Predicting Low-Probability/High-Consequence Events," Proceedings of the Workshop on Low-Probability/High-Consequence Risk Analysis, June 15-17, 1982, Arlington, Virginia.~~
- ~~ICOLD (1995), "Dam Failures Statistical Analysis," Bulletin 99, International Commission on Large Dams.~~
- ~~Foster M, Fell R, Spannagle M (2000a), "The statistics of embankment dam failures and accidents," *Canadian Geotechnical Journal*, 37, 1000-1024.~~
- ~~Foster M, Fell R, Spannagle M (2000b) "A method for assessing the relative likelihood of failure of embankment dams by piping," *Canadian Geotechnical Journal*, 37, 1025-1061.~~
- ~~Donnely, R. (2004), "Issues in Dam Safety," ACRES International Innovations Autumn Edition~~
- ~~U.S. Bureau of Reclamation, "A Framework for Characterizing Extreme Floods for Dam~~

~~Safety Risk Assessment," U.S. Department of the Interior, Technical Service Center, Denver, CO, 1999.~~

- ~~U.S. Bureau of Reclamation, "Dam Safety Risk Analysis Methodology," Version 3.3.1, U.S. Department of the Interior, Technical Service Center, Denver, CO, 2003.~~

- ~~U.S. Bureau of Reclamation, "Dam Safety Risk Analysis Best Practices Training Manual," Version 2.0, U.S. Department of the Interior, Technical Service Center, Denver, CO, 2010.~~

~~DISCUSSION~~

~~While revisiting this estimate, the~~ NRC staff recently reviewed the use of dam failure frequency estimates in NSAC/60. The NRC staff noted that many assumptions in the dam failure rate estimation approach used in NSAC/60 are strongly dependent upon the completeness and accuracy of the dam data used and the criteria for including or excluding certain failure events and operational years deemed to be applicable to characteristics specific to the dam considered in NSAC/60 (i.e., type, height, construction year, and years of operation). In particular, the failure frequency derived in NSAC/60 was considered to be representative of failure modes resulting from causes other than hydrologic (e.g., severe precipitation), and seismic events~~,~~ which NSAC/60 states were considered in separate analyses. In effect, this choice of exclusions eliminates the majority of failure modes that has been historically observed for dams (e.g., overtopping). Additionally, the phenomena associated with non-hydrologic, non-seismic (e.g., internal erosion/degradation) events was further screened for other failures modes not deemed applicable based on design considerations also specific to the ~~dam considered in the study~~Jocassee dam (i.e., piping through a conduit passing through the dam, and structural failures of the spillway during flood discharge).

To assess the impact of ~~these~~the NSAC/60 screening assumptions, the NRC staff reviewed currently available ~~US~~ databases for ~~both~~ U.S. dams. In order to determine generic dam failure frequencies, the databases are used find (i) the number of historical failures of dams of a particular characteristic such as dam type and (ii) the total number of years of operation of dams of the same characteristic. The NRC staff reviewed databases of historical dam failure events~~(~~, primarily~~,~~ the National Performance of Dams Program by Stanford University~~) and the~~, http://npdp.stanford.edu/index.html, and the database of the existing population of ~~US~~U.S. dams ~~(~~, the National Inventory of Dams maintained by the ~~US~~U.S. Army Corps of Engineers~~) that provide~~ (USAEC), http://nid.usace.army.mil). [While USACE Web site states "Non-government users are no longer able to directly download any data from this site," non-government users can request access to the data by contacting the USACE staff member specified on this Web site.] While these databases contain valuable historical information and are certainly more complete and accurate than information than available when NSAC/60 was prepared. ~~While valuable historical information is contained in both databases, the NRC staff also observed~~, the NRC staff found inherent challenges in using the databases for PRA purposes that limit the ability to soundly justify a very low value of dam failure frequency using only historical data. The databases were not created for the specific purpose of performing dam PRAs and were not designed to be used together. As such, the NRC staff found that data was not always complete,

consistent, and sufficiently detailed for use in PRAs. For instance, NRC staff found that for PRA purposes there was an inherent challenge regarding the incompleteness of failure event accounts (e.g., construction year of failed dam, and failure mode), sparse data and inconsistencies on definitions used on both failed and operating dams (e.g., dam types).

~~In addition~~To understand the impact these inherent databases challenges, the NRC staff ~~also~~ performed analyses of the ranges of generic dam failure frequency estimates that can be derived from these databases~~, as well as a~~. The NRC staff also reviewed literature ~~review~~ on previously published dam failure rates. The NRC staff also reviewed literature ~~review included~~ on published ~~analyses~~dam PRAs mostly based on historical evidence for the ~~US~~U.S. and the international population of dams~~: Baecher et al (1980); Martz and Bryson (1982); ICOLD (1995); Foster *et al* (2000a); Foster *et al* (2000b); Donnelly (2004); and USBR (2010). From both efforts, the~~. The NRC staff also reviewed available information ~~gathered provides significant evidence~~on the latest dam risk assessment methodologies including the following publications from the U.S. Department of Interior's Bureau of Reclamation at http://www.usbr.gov/library/: "A Framework for Characterizing Extreme Floods for Dam Safety Risk Assessment," issued 1999; "Dam Safety Risk Analysis Methodology," Version 3.3.1, issued 2003; and, "Dam Safety Risk Analysis Best Practices Training Manual," Version 2.0, issued 2010.

Based on this review, the NRC staff determined that generic dam failure ~~frequencies~~frequency estimates that are considerably lower than 10^{-4}/year may not be justifiable based only on historical dam performance information. ~~Additionally, as stated in NUREG/CR-5042, dam failure rates above this value are also possible and, therefore, a technical justification would have to be provided in support of any specific estimate used.~~ This is due to the variability on site-specific characteristics (i.e., hydrologic, geologic, and operational) and the potential contributions of site-specific failure modes not covered by databases, such as the potential activation of failure modes in dams which have never been filled beyond a certain operational reservoir level (e.g., first-fill scenarios). This is compounded by the data analysis challenges discussed above. ~~In reaching this conclusion, the NRC staff also considered available information on current state-of-art methodologies in risk assessment of dams published by multiple sources, including federal agencies such as the US Department of Interior's Bureau of Reclamation (e.g., USBR, 1999; USBR, 2003).~~

~~In conclusion,~~**DISCUSSION**

Both NSAC/60 and NUREG/CR-5042 are commonly used primary reference documents for licensees performing external flooding analyses incorporating a dam failure and applied to any type of dam. However, recent NRC reviews determined that the generic failure frequency estimate used in NSAC/60 combined generic information with site-specific screening criteria that produced median values an order of magnitude lower than published literature and NRC staff's assessments support. Consideration of data sources currently available also indicates that (i) such significantly lower values may not be justified by historical data alone, and (ii) applicability of the NSAC/60 estimate to other dams with different characteristics may be inappropriate. Reasons for ~~these conclusions~~this include the fact that generic failure frequency values may not account for site-specific features and can be highly dependent on completeness and applicability of available information to site-specific dams; which may counteract conservative

assumptions in the use of data.

These considerations recognize that data available in these databases is useful in deriving bounding values and approximate generic dam failure rate estimates, but that the justification for its use in obtaining significantly lower values than the established averages may not be conservative may result in inappropriate estimates of the risk of external flooding or loss of ultimate heat sink, depending upon how such dam failure frequencies were used. Although there is no specific regulatory requirement to do so, licensees may use this readily available dam data to develop a facility-specific dam data set in order to update the dam failure frequency value specified in their PRA for external events.

CONTACT

This information notice requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below.

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Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

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These considerations recognize that data available in these databases is useful in deriving bounding values and approximate generic dam failure rate estimates, but that the justification for its use in obtaining significantly lower values than the established averages may not be conservative ~~and therefore inappropriate for screening purposes.~~may result in inappropriate estimates of the risk of external flooding or loss of ultimate heat sink, depending upon how such dam failure frequencies were used. Although there is no specific regulatory requirement to do so, licensees may use this readily available dam data to develop a facility-specific dam data set in order to update the dam failure frequency value specified in their PRA for external events.

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