UNITED STATES
NUCLEAR REGULATORY COMMISSION
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January 6, 2016

LICENSEE: Entergy Operations, Inc.

FACILITY: Arkansas Nuclear One, Units 1 and 2

SUBJECT: SUMMARY OF OCTOBER 28, 2015, CLOSED MEETING BETWEEN REPRESENTATIVES OF THE U.S. ARMY CORPS OF ENGINEERS, U.S. NUCLEAR REGULATORY COMMISSION, AND ENTERGY OPERATIONS, INC. TO DISCUSS THE FLOOD ANALYSIS ASSOCIATED WITH ARKANSAS NUCLEAR ONE, UNITS 1 AND 2 (TAC NOS. MF3041 AND MF3042)

On October 28, 2015, the U.S. Nuclear Regulatory Commission (NRC) staff held a closed meeting with the U.S. Army Corps of Engineers (USACE), and Entergy Operations, Inc. (Entergy), to discuss the flood hazard reevaluation (FHR) for the Arkansas Nuclear One, Units 1 and 2 (ANO). The meeting was held at USACE's offices in Little Rock, Arkansas. The closed meeting notice dated October 21, 2015, can be found in the Agencywide Documents Access and Management System (ADAMS) at Accession No. ML15292A241. The list of attendees can be found as Enclosure 1 to this summary. Entergy provided a list of questions associated with the USACE FHR for the ANO site. These questions were discussed during the meeting. The questions and answers can be found in Enclosure 2 to this summary.

The purpose of the meeting was to discuss the portion of the FHR the USACE is performing under contract to the NRC for ANO. By letter dated September 30, 2014, Entergy requested NRC assistance in having the USACE perform a dam failure analysis for the Arkansas River watershed for ANO (ADAMS Accession No. ML13275A067). Entergy requested the NRC's assistance to support Entergy's development of an ANO flood hazard reevaluation report (FHRR) in response to the March 12, 2012, request for information issued pursuant to Title 10 of the *Code of Federal Regulations* Part 50, Section 50.54(f) (ADAMS Accession No. ML12073A348).

The USACE and NRC provided Entergy with preliminary results of the USACE dam failure analysis. The NRC stated that the next action to be completed in the process is the transmittal of the final results to Entergy. The NRC also stated that Entergy could request another meeting with the NRC after receiving the results.

The USACE was provided an opportunity to comment on this summary prior to its issuance and its comments were addressed in the final version of this summary.

If you have any questions, please contact me at (301) 415-2915 or e-mail at Victor.Hall@nrc.gov.

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Office of Nuclear Reactor Regulation

Docket Nos. 50-313 and 50-368

Enclosures:
1. List of Attendees
2. Entergy Questions and Answers

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US Army Corps of Engineers® / U.S.NRC United States Nuclear Regulatory Commission, *Protecting People and the Environment*	NRC/USACE Intermediate Technical Review (ITR) Meeting Arkansas Nuclear One, Units 1 and 2 October 28, 2015 USACE, Little Rock District Headquarters CESWL-RD 700 West Capitol Avenue, Room 4329 Little Rock, AR 72201-3221

LIST OF ATTENDEES:

NRC:	Andy Campbell*, John Dixon*, Victor Hall, Brad Harvey, Jeff Mitman*, Ken See
USACE Omaha:	Roger Kay, Curtis Miller, Teresa Reinig
USACE Little Rock:	David Blackmore, Henry Himstedt, Nathaniel Keen, Glenn Proffitt, Padmanabhan Rajendran, David Williams
Entergy:	Don Bentley, Mike Krupa, Stephenie Pyle
Areva (Entergy):	Daniel Brown
GZA (Entergy):	Chad Cox, David Leone

*via teleconference

Entergy Operations, Inc. Questions Associated With U.S. Army Corps of Engineers Flooding Hazard Reevaluation

Probable Maximum Precipitation

1. How did USACE use [hydrometeorological Report] HMR51/52 or other HMRs to derive a [probable maximum precipitation] PMP for [Arkansas Nuclear One, Units 1 and 2] ANO given that the 153,000 square mile Arkansas River basin is much larger than the 20,000 square mile upper limit of HMR 51/52? For example:

a. Were depth-duration curves extrapolated?

b. Were multiple storms used?

c. Was a moving storm evaluated?

d. What were the critical storm orientations and center locations?

e. What temporal distributions were considered and which was critical?

f. How were physical, meteorological limitations on storm duration and area included in the analysis?

g. How was the upper (western) part of the watershed evaluated where HMR55A is the controlling HMR, as it uses different methods and data than HMR51/52?

USACE/NRC Response:

a. USACE did not extrapolate the depth-duration curves. USACE analyzed 14 storms with 72 hour durations to develop a maximum enveloping curve used for the analysis.

b. USACE analyzed 14 storms to develop the depth-area-duration data to produce the maximum envelope for the analysis. USACE followed all appropriate guidance in developing the PMP.

c. USACE did not use a moving storm.

d. USACE used the 1943 Warner storm for storm orientation and centering to produce the maximum precipitation.

e. The original design hydrology for Dardanelle was used for this project, which kept the 1943 Warner storm in place (no transposition or rotation). The orientation of this storm as it occurred produced maximum rainfall near Okemah, Oklahoma; this location was considered to be the critical center both in the original design of the project as well as in this project.

f. USACE analysis considered durations out to 72 hours over the full areal distribution of each storm, some of which exceeded 200,000 sq. mi.

g. USACE did not look at storms west of the 105th Meridian. The major storms for the region occurred east of the 105th Meridian; therefore HMR55A was not necessary.

2. **If HMRs were used, were any more recent data or new storm re-analysis (e.g., not included in the 40+ year old HMR51 and 30+ old HMR55A) considered when using the HMR analysis of older storms?**

USACE/NRC Response: USACE looked at a range of storms, including recent storm events. The dates of the storms ultimately considered ranged from 1899 to 2007.

3. **Was HMR-derived information vetted or peer-reviewed either internally within USACE or by the [National Weather Service] NWS or other experts? If so, how were updated data, meteorological understanding, and techniques to develop PMP integrated?**

USACE/NRC Response: All data and analysis were peer-reviewed within USACE by personnel in multiple USACE Districts.

4. **If applicable, please provide a technical justification for application of generalized HMR information to the ANO watershed specifically given its large area (beyond HMR limitations), unique setting (in contrast to generalized estimates from HMRs), lack of storm data from the last 40 years, and its geographic coverage (enveloping multiple HMR documents / regions).**

USACE/NRC Response: N/A – Generalized HMR data were not used in the USACE analysis.

5. **How was NRC guidance, specifically the Hierarchical Hazard Assessment Approach, applied during the calculation of the PMP?**

USACE/NRC Response: USACE guidance was followed in developing the PMP. The USACE and the NRC approach are similar; the only difference is USACE guidance requires use of the 1968 Climatological Atlas while NRC guidance allows the use of the current Atlas. However, based on a comparison of the licensee's PMP and the USACE PMP, there is little difference in the depth-area-duration relationships.

6. **If site-specific PMP results are presented, please discuss the following:**

   a. **How did the methodology USACE used differ from the methodology used in the draft reevaluation methodology?**

   b. **Was any other input data beyond what was used in the draft reevaluation site specific PMP calculation used and, if so, why?**

c. Please discuss the development and identity of the short list of storms used for site-specific PMP development.

USACE/NRC Response:

a. Overall, the USACE and licensee used similar methodology in the development of the PMP. A major difference between the two analyses is that the licensee did not use the procedure described in HMR 51 for the development of maximum persisting dew-point temperatures. Another difference between the two analyses is the licensee's use of a different climatological dataset than the 1968 Climate Atlas. A comparison was made of both methodologies, and the results did not show any significant difference in depth-area-duration relationships. The licensee showed a slight higher envelope for areas less than 3000 sq. mi. while the licensee and USACE envelope curves were nearly identical for areas greater than 3000 sq. mi.

b. No other data were used.

c. Large regional storms were selected from the HMR 51 Important Storms

Appendix. More recent storms were identified from flood records and were subsequently analyzed. The following storms were selected for analysis:

Hearne, TX (1899), Meeker, OK (1908), Neosho Falls, KS (1926), Mounds, OK (1932), Cheyenne, OK (1934), Index, AR (1940), Hallett, OK (1940), Warner, OK (1943), Council Grove, KS (1951), Albany, TX (1978), Clyde, TX (1981), Big Fork, AR (1982), Fort Scott, KS (1986), Watonga, OK (2007)

<u>Probable Maximum Flood (Hydrology and Hydraulics)</u>

7. Did the USACE independently initiate and develop a Probable Maximum Flood [PMF] flow hydrograph using its own hydrologic (rainfall-runoff) computer model? If so, please provide the following:

a. Identify the computer model used.

b. Describe the hydrologic methodology used to develop the inputs to the hydrologic model (e.g., unit hydrograph method, transform used, precipitation losses considered, etc.).

c. How was the watershed divided into subwatersheds? How many subwatersheds were used?

d. What base flow was assumed?

e. The watershed is highly regulated, with over 1,700 flood control dams and over 5,200 dams in total. Please identify the dams individually modeled in the hydrologic model and their initial conditions. To the extent possible,

please describe the operating assumptions of the dams (particularly large flood control dams) during the PMF.

f. Describe the calibration and verification of the hydrologic model, including identification of calibration and verification storms and meteorological data. How did model results compare to observed hydrographs (peak discharge, volume, and timing for subwatersheds and at the watershed outlet)? Which stream gages were used for comparison?

USACE/NRC Response:

a. EM 1110-2-1408 and original design guidance were used in the development of the routing, which was performed in a computer spreadsheet.

b. Synthetic unit hydrographs were developed for the various areas by methods described in EM 1110-2-1405. Consideration was given to available unit hydrograph data, flood data at the above stations, weighted stream slopes, vegetative cover, and topography. The weighted stream slopes of the various tributaries varied from 0.000064 to 0.00674. Snyder's coefficient C_t varied from 1.0 to 3.8 and $C_{p\,640}$ from 340 to 550. All flood routing criteria were adjusted for use with time increments of 6 hours. Preliminary studies of the intervening areas indicated a variable storage discharge relationship, especially on the lower Verdigris River. Therefore, flood routing curves were developed for the reaches in the lower area using the R-D method of routing described in EM 1110-2-1408.

c. The watershed was divided into subwatersheds, or subbasins, with a total of 17 subwatersheds developed in conjunction with other studies.

d. There were about 160 stream gaging stations that were used to determine the base flow for all subbasins within the model.

e. The following dams were studied independently and the results of their study were used for the development of the hydrologic model for Dardanelle and ANO: Keystone Dam, Robert S. Kerr, Oologah Dam, John Redmond Dam, and Eufaula Dam. The starting conditions were set at full pool for each of these dams for development of the PMF.

f. Major floods of record were used in the development and testing of the unit hydrographs and flood routing criteria. In each reconstitution, the flows at the upstream gages were routed to the downstream gage, combining the flows from the intervening areas at each reach. The computed hydrographs for seven floods were compared with the observed hydrographs along with rainfall and rainfall excess data on the intervening areas. Five additional floods were studied and good overall reproductions were attained with computed results within 4 to 10 percent of observed peaks.

8. Was the PMF an all-season event, or was snowmelt a factor?

USACE/NRC Response: Snowmelt was not a factor in the analysis.

9. How was NRC guidance, specifically the Hierarchical Hazard Assessment Approach, use of 40% of the PMP as an antecedent storm, and adjustments for nonlinearity, applied during the calculation of the PMF flow hydrographs?

USACE/NRC Response: USACE guidance was followed, which calls for an antecedent storm that is 50% of the PMP. The original Warner storm in place was used for the analysis as it was the critical actual storm used during the design.

10. Did the USACE independently initiate and develop a Probable Maximum Flood water surface profile using its own hydraulic computer model? If so, please provide the following:

a. Identify the computer model used and the methodology employed (e.g., steady flow, unsteady flow; one-dimensional or two-dimensional).

b. Discuss the extents (upstream and downstream of ANO) of the model.

c. Describe the dams and bridges included in the model.

d. Discuss the model inputs including the selection and value of Manning's n roughness coefficients, stream and floodplain geometry, and cross section spacing.

e. Describe the operating assumptions and/or any internal boundary conditions (rating curves, gate and/or lock openings, etc.) for any locks and dams in the model. In particular, please describe the assumptions used in the model for the Lake Dardanelle Lock and Dam.

f. Describe the downstream boundary condition for the model.

g. Describe the calibration and verification of the hydraulic model, including identification of calibration and verification storms and the identity and number of gage locations used for comparison. How did model results compare to observed water surface profiles or recorded stage values?

USACE/NRC Response: USACE used existing models available for the Arkansas River system and tributaries to route the PMF hydrographs for all projects. The models were developed in conjunction with the USACE Modeling, Mapping and Consequences Center, which provides guidance on production of dam break modeling for consequence assessments for all USACE dams.

a. The USACE model was a combination of individual [Hydrologic Engineering Center-River Analysis System] HEC-RAS models combined into a single system model. The models were initially developed with HEC-RAS 4.1. The combined system model was developed using HEC-RAS 5.0 Beta. This program is approved for use by USACE and was used since it has improved features for mapping. All scenarios were run using the 1-D unsteady flow regime and included tributary reaches, storage areas, inline structures and bridges. No 2-D elements were included in the model.

b. The downstream extent was about 2 miles below Dardanelle L&D on the Arkansas River. The upstream extents included the main stem Arkansas River and all tributaries with potentially critical dams and with significant operational dams in order to capture residual flows for all scenarios. The potentially critical dams were included in the model as Inline Structures along the necessary tributaries. Reaches included over 200 miles of the Arkansas River from below Dardanelle L&D to Keystone Dam, Poteau River system, Illinois River to Tenkiller Dam, Canadian River to Eufaula Dam, Neosho River to include Fort Gibson, Markham Ferry and Pensacola Dams, the Verdigris River, Bird Creek and Hominy Creek up to Skiatook Dam and Oologah Dam.

c. All dams and L&D structures were modeled as inline structures. Operations of the dams were input using elevation control as well as rule sets. Rating curves were taken from the pertinent Water Control Manuals. All bridges in the system below the dams are included in the model, as bridges can impact timing and magnitude of the flood wave. The Arkansas River bridges are generally high structures as the river is a navigable reach, but pier locations and low chords were modeled to capture any potential impacts to routing.

d. Manning's roughness values were taken from the original modeling. The original models were calibrated to a range of flows based on the observed data. Floodplain geometry was taken from the [U.S. Geological Survey] USGS 10m base data and updated with shuttle run, LiDAR and any other more recent and pertinent data. Bathymetric surveys in the navigable reaches were used for the below water geometry in the navigable reaches. Below water geometry on the tributaries was taken from gage cross sections, degradation range surveys and in some cases estimated based on a trapezoidal section. All reaches were calibrated to ensure that channel capacity flow rates were within channel. Cross section spacing is based on guidance provided in the HEC-RAS manual and as noted in USACE modeling guidance as appropriate for the computation interval.

e. All projects were modeled as Inline Structures and utilized operational controls of elevation and rules. The L&D structures, including Dardanelle, operate as run-of-river and do not have flood storage capability. Rating curves and operational openings were taken from the Water Control Manual and confirmed with gage data when available.

f. The downstream extent is about 2 miles below Dardanelle L&D. The normal depth assumption was used with a slope estimation based on the river bed slope up to Dardanelle. A known rating curve was input at Dardanelle in order to capture true headwater values through the Dardanelle Structure.

g. The calibration effort includes gage calibration for several locations below flood stage. Historic events form 2007 and 2011 were also used to calibrate to events above flood stage. The reference design flood for each project was also used as an extreme event storm to test for reasonableness of results. The system model was run for a range of flows and results compared to the rating curve at Van Buren, with only minor adjustments warranted to the model data to match the rating curve. Van Buren was selected as a comparison point as it is the critical stage point for all operations in the Upper Arkansas River system.

11. How was NRC guidance, specifically the Hierarchical Hazard Assessment Approach, applied during the calculation of the PMF water surface profile?

USACE/NRC Response: USACE and NRC guidance was followed in developing PMF water surface profiles. Each project was looked at individually and as a system of operating dams by USACE. An assessment of historical data and team assessments and evaluations was used to develop a list of potential failure modes. An estimation of the flood hazards from each potential failure mode was determined and used as part of the assessment. USACE verified that all hydrology and hydraulics used in the evaluation followed current USACE guidance and was updated as needed.

<u>Dam Failure Evaluation</u>

12. The USACE described the initial screening results at the July 16, 2014 meeting. At that time, seven dams were preliminarily identified as being potentially critical. Please describe any changes to the methodology and results that may have occurred after the July 16, 2014 meeting with a particular focus on screening non-critical and potentially critical dams.

USACE/NRC Response: No changes to methodology or results relative to screening potentially critical dams were identified subsequent to the July 16, 2014, meeting.

13. Were seismic or sunny day failures evaluated? If seismic failures were evaluated, please describe the development of the coincident flood (i.e., the 500-year flood or the ½ PMF).

USACE/NRC Response: Sunny day failures of the eight dams identified to be potentially critical were evaluated, even though the volumes from this failure mode were significantly smaller and the NRC's staff position provided an exception (2d bullet, Page 6-1) that did not require this work. The analysis of the sunny day and hydrologic failures brackets the catastrophic flood risk at the site. Seismic failures were determined to be not required since the seismic parameters at each of the eight potentially critical dam sites were below the threshold values prescribed in the USACE guidelines.

14. Please describe the modeling methodology for potentially critical dams. Was the failure of potentially critical dams simulated using hydrologic modeling methods (i.e., HEC-HMS [Hydrologic Modeling System]) or hydraulic modeling methods (i.e., unsteady HEC-RAS)?

USACE/NRC Response: Unsteady HEC-RAS modeling was used to simulate and analyze the failure of all potentially critical dams. A discussion of potential failure modes were reviewed in conjunction with USACE and NRC guidance.

15. Did the evaluation failure of non-USACE dams use reference information from other sources / dam owners? If so, can such information be shared with Entergy?

USACE/NRC Response: Evaluation of potential failure modes of non-USACE dams was conducted in cooperation with the respective dam owners, and none of these non-USACE dams were found to have any credible potential failure modes. If Entergy should later desire to see data related to these projects, the dam owners should be contacted directly about their policy for releasing records to private entities.

16. Please describe the failure triggers for hydrologic dam failure.

a. Was site-specific (e.g., specific to each dam) information used to identify failure?

b. Were any potentially critical dams assumed or calculated to fail hydrologically which were not overtopped by the PMF?

c. Were dams assumed to reach their maximum pool prior to failure, or was a generic or site-specific threshold elevation (e.g., x feet above top of dam for erodible embankments) used?

USACE/NRC Response:

a. Yes, the USACE team followed current USACE methodologies in identifying and assuming any potential failure modes.

b. Four dams had non-overtopping potential failure modes identified during a PMF event occurring upstream of each of these four individual dams and were assumed to fail for this analysis.

c. Potential failure modes for any dam were evaluated on the basis of construction records, geological and geotechnical data, inspection reports, performance and hydraulic loading. Each of the identified potential failure modes was associated with PMF pool levels.

17. For hydrologic dam failures, please describe the hydrologic storm scenarios evaluated. Specifically, please describe the coincident hydrologic flood in terms of storm center location, orientation, duration, and storm area. For example, were storms centered or located in the watershed of each potentially critical dam (separately or in a combined manner) or was the overall Arkansas River PMF the only hydrologic scenario considered?

USACE/NRC Response: The PMF specific to each dam was considered in addition to the overall Arkansas River PMF at ANO.

18. Please discuss the timing of the dam failures evaluated.

a. How were intrinsic timing effects for the flood wave to reach ANO due to the disparate locations of the potentially critical dams incorporated into the model? For example, were dams assumed to fail simultaneously or as a function of their upstream reservoir level?

b. Were dam breach flood waves routed separately (hydrologically and/or hydraulically) or combined (to simplify modeling)?

USACE/NRC Response:

a. Dam failures were analyzed separately for each dam. The PMF was routed through the project with failure occurring at the peak pool. The potential failure mode was determined based on the team's assessment for each dam.

b. All routings were conducted using HEC-RAS to compute the flood wave attenuation from the assumed dam failure downstream to Dardanelle L&D.

19. Please discuss the critical hydrograph at ANO as a result of the dam failure analysis.

a. Please include a description of coincident hydrologic flows, identification of the cause of multiple peaks (if applicable) and commentary on the volume and duration of the flood.

b. Given the anticipated magnitude of the flood, please discuss the effects (if any) of operations at USACE flood control and navigational facilities on the maximum flood elevation and duration at ANO. Please describe any sensitivity analyses performed to account for operational uncertainties at these structures.

USACE/NRC Response:

a. The critical hydrograph at ANO is based on the Dardanelle PMF with a potential failure at Robert S Kerr L&D. The coincident flows along the system were such that flooding occurs prior to assumed failure. Discharges in the Arkansas River at Van Buren were about 300,000 cfs prior to failure. This flow rate has been observed in historic floods in 1986, and in 2007, and is considered a reasonable level of residual discharge based on expected operation of the flood control system.

b. The impacts of operational uncertainties are minimal. Assuming that all flood control projects do not fail and are limited to operational discharges the magnitude of the discharges would be less than roughly 50% of the critical hydrograph peak. It is unlikely that all projects in the system would experience PMF inflow at the same time and of like durations.

20. How was NRC guidance, specifically the Hierarchical Hazard Assessment Approach and the processes outlined in JLD-ISG-2013-01, applied during the calculation of dam failures?

USACE/NRC Response: USACE followed NRC guidance document JLD-ISG-2013-01 for the screening and the more detailed analysis processes. Section 3.2 outlines the simplified modeling approaches and it is these methods that constitute the hierarchical-hazard-assessment (HHA). In its screening process, USACE used the Volume Method as explained in Section 3.4 of the Engineering Screening Report. This method produced a list of 24 potentially critical dams. USACE then used the peak outflow with attenuation method with a simplified dam break analysis following U.S. Bureau of Reclamation procedures to further screen the list of dams. This method reduced the list to seven upstream dams. Because Huckleberry Creek Dam is not situated upstream from ANO but is on a tributary to the Arkansas River with its confluence adjacent to ANO, a rough order of magnitude routing model was used for evaluation. This results of this method indicated Huckleberry Creek Dam should be included for more detailed analysis.

USACE continued this thought process into the evaluation of the eight dams identified as potentially critical. USACE modeled certain scenarios, for example sunny day failure, that may not have been necessary for every dam based upon the ISG staff position. However, by doing so, USACE demonstrated a hierarchical-hazard-assessment approach whilst conducting its more detailed analysis. Similarly for the hydraulic modeling, USACE investigated various ranges of roughness to ensure that the hydrograph generated produced results within a reasonable range at the ANO site.

If you have any questions, please contact me at (301) 415-2915 or e-mail at Victor.Hall@nrc.gov.

/RA/

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Docket Nos. 50-313, and 50-368

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