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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
DUKE ENERGY CORPORATION	)	Docket Nos. 50-413-OLA
	)	50-414-OLA
(Catawba Nuclear Station, Units 1 and 2)	)	

NRC STAFF'S REPLY FINDINGS OF
FACT AND CONCLUSIONS OF LAW
CONCERNING BREDL CONTENTION I

INTRODUCTION

In accordance with the Atomic Safety and Licensing Board's (Board) scheduling order,[1] proposed findings of fact and conclusions of law concerning the Blue Ridge Environmental Defense League's (BREDL) Contention I were timely filed by Duke Energy Corporation (Duke), BREDL, and the NRC staff (Staff).[2] Pursuant to the Board's Order, the Staff herein files its reply to the proposed findings of fact and conclusions of law that were filed by Duke and BREDL concerning Contention I.

APPLICABLE LEGAL STANDARDS

2.5. In its proposed findings of fact, BREDL expressed concern about the applicability of 10 C.F.R. § 50.46 and Appendix K. In particular, the applicability of three of the acceptance criteria in 10 C.F.R. § 50.46 with regard to the use of mixed oxide (MOX) fuel: peak cladding temperature (PCT), maximum cladding oxidation, and coolable geometry. Blue Ridge

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[1] *Duke Energy Corp.* (Catawba Nuclear Station Units 1 and 2), Order (Regarding Proposed Redacted Memorandum and Order, and Proposed Schedule Changes), Docket Nos. 50-413-OLA & 50-414-OLA, ASLBP No. 03-815-03-OLA (May 25, 2004).

[2] Duke Energy Corporation's Proposed Findings of Fact and Conclusions of Law Regarding Contention I (Aug. 6, 2004) (Duke's Proposed Findings); Blue Ridge Environmental Defense League's Proposed Findings of Fact and Conclusions of Law Regarding Contention I (Aug. 6, 2004); NRC Staff's Proposed Findings of Fact and Conclusions of Law Concerning BREDL Contention I (Aug. 6, 2004) (Staff Proposed Findings).

Environmental Defense League's Proposed Findings of Fact and Conclusions of Law Regarding Contention I (BREDL Proposed Findings) at 3 (Aug. 6, 2004). For a number of reasons, however, BREDL agrees that it is generally appropriate to apply the requirements of 10 CFR § 50.46 to MOX fuel as long as Appendix K is not strictly applied to exclude consideration of relocation of the fuel during loss of coolant accidents (LOCAs).[3] BREDL Proposed Findings at 4-5; Transcript (Tr.) at 2564, 2604. Thus, the outcome of this issue turns on whether an Appendix K analysis that does not explicitly include the effects of fuel relocation is adequate for the MOX lead test assemblies (LTAs) in the Catawba Nuclear Station (Catawba).

2.6. Appendix K is silent about the phenomenon of fuel relocation. *See* 10 C.F.R. Part 50, App. K. BREDL contends that an early "resolution" of this issue (*i.e.*, Generic Issue 92) may have been in error. BREDL Proposed Findings at 4. In support of this assertion, BREDL cites to an NRC memorandum, offered as Exhibit 26. However, this memorandum on its face does not support BREDL's arguments. Exhibit 26, in fact, makes clear that the low priority ranking of the significance of the issue was found to be in error, but that the issue itself had never been resolved.

2.7. BREDL also contends that, more recently, NRC has acknowledged that omission of fuel relocation effects is a non-conservatism in Appendix K with a potential impact on PCT and that NRC contemplated requiring fuel relocation to be included in Appendix K models. BREDL Proposed Findings at 3-4. In support of these statements, BREDL relies on a memorandum from Ashok C. Thadani (Exhibit 27). This reliance, however, is misplaced because Exhibit 27, on its face, does not support BREDL's arguments. First, the memorandum states that "it remains technically acceptable to retain all of the existing requirements in 10 CFR § 50.46 and Appendix K in their present form as an option such that no model changes or reanalysis would be required." Ex. 27 at 2. Second, the memorandum talks about a revised Appendix K and says that "[a]s known

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[3] "Relocation" of fuel, as discussed herein, refers to the movement of fragmented fuel to a ballooned section of cladding in a fuel assembly during a LOCA.

conservatism is removed from Appendix K . . . there must be a process to ensure that calculations based on a revised version of Appendix K retain appropriate conservatism." *Id.* The memorandum also states that "*new* evaluation models making use of a revised, optional Appendix K should conservatively account for" fuel relocation and two other non-conservative phenomena. *Id.* at 3 (emphasis added). The memorandum thus demonstrates that the NRC contemplated requiring fuel relocation to be included in Appendix K models *only* when other changes would reduce the overall conservatism of Appendix K. However, there have been no amendments to Appendix K since the Thadani memo. *See* 10 C.F.R. Part 50, Appendix K.

2.8. Based on the foregoing, the Board agrees with Duke and the Staff that Appendix K contains positive and negative conservatisms and does not need to be modified to account explicitly for fuel relocation. *See* Ex. 27 (discussing the conservatisms and non-conservatisms in Appendix K). Further, although BREDL has alleged that the relocation effects in MOX fuel might be worse than they are in LEU fuel, the record does not support that position. Therefore, we find that Duke's use of Appendix K models, without consideration of fuel relocation, for the MOX LTAs at Catawba provides adequate protection of public health and safety.

<u>FINDINGS OF FACT</u>

4.43. BREDL suggests that fuel relocation would have an effect on PCT, maximum cladding oxidation, and coolable core geometry. *See* BREDL Proposed Findings at 3. Although research regarding the effect on cladding temperature is not conclusive, the Staff agrees that fuel relocation might cause the cladding temperature in the balloon to increase by several hundred degrees Fahrenheit.[4] Tr. at 2307. However, this phenomenon does not equate to a large impact on PCT for the hottest fuel rod in the core because the PCT generally occurs away from the balloon

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[4] The "balloon," as discussed herein, refers to the deformed region of cladding material attributed to pressure-driven expansion at high temperature during a LOCA.

(Tr. at 2305) as is the case for Catawba. *See* Ex. 1, Table 3.5. In fact, as BREDL's witness, Dr. Lyman, pointed out, when relocation occurred in the FR2 test E4 (Duke Testimony, Fig. 11 at 47.) the data showed that the maximum temperature in the ballooned region was still about 20°F below the PCT, which occurred away from the balloon. BREDL Proposed Findings at 8; Tr. at 2153.

4.44. Although the phenomena are quite complicated, both the Staff and BREDL made simple estimates of the effect of fuel relocation on cladding temperature at the rupture location in the balloon. Dr. Lyman started with a value of 1841°F, which was taken from a preliminary sample calculation submitted by Duke in the LAR at 3-43. To this Dr. Lyman added 313°F from an early French study at the Institute for Protection and Nuclear Safety (IPSN), plus an extra 20°F, to get a resulting cladding temperature at the rupture location of 2174°F. BREDL Proposed Findings at 9. The Staff started with a value of 1750° F, which was taken from the actual Catawba MOX LTA licensing analysis (Duke Testimony at 22; Tr. at 2500). To this the Staff added 270°F from a more recent French study at the Institute of Radioprotection and Nuclear Safety (IRSN, formerly IPSN) to get a resulting cladding temperature at the rupture location of 2020°F. Staff Proposed Findings at 18; Tr. at 2635-36. During cross examination, neither Dr. Lyman nor Dr. Meyer could explain the apparent discrepancy in the IRSN graph. The graph appeared to show a maximum increase of about 360°F (200°C), whereas the note on the graph said the maximum increase was 270°F (150°C). Tr. at 2661-2662. Nevertheless, even if one uses the higher value (360°F) and adds that value to 1750°F, the correct value for Catawba, the resulting cladding temperature at the rupture location is 2110°F.

4.45. Three observations are apparent to the Board. First, all of the estimates cited above used the maximum values of temperature increase, which correspond to the highest degree of particle packing considered in the IPSN and IRSN studies. See Ex. 31; Ex. 41. *Second*, all of the estimates of the effect of fuel relocation on PCT result in a temperature below the regulatory limit of 2200°F. Third, such a relocation penalty should not be applied to PCT calculated with Appendix K models because these models already contain compensating extra conservatisms such as those described in NRC's Research Information Letter 0202 (Exhibit 27). *See also* Tr. at 2312.

4.46. Simple estimates were also made of the effect of fuel relocation on the maximum cladding oxidation in relation to the 17% limit in 10 C.F.R. § 50.46(b)(2) ("The calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation"). The IPSN study evaluated the impact of relocation on the maximum cladding oxidation for the ruptured region. Ex. 29. IPSN found 12.6% for the no-relocation case and 19.7% for the relocation case with the largest filling ratio considered in the study (70%).[5] *Id.* Thus, the maximum impact on oxidation resulting from relocation was calculated to be 7.1%. BREDL Proposed Findings at 12.

Using this maximum impact of 7.1% as an estimate of the impact of fuel relocation in Catawba and adding it to the maximum local oxidation of 3% calculated at the ruptured location in the MOX fuel results in a total maximum cladding oxidation of about 10%, which is lower than the 17% limit in 10 CFR 50.46. Tr. at 2175. Dr. Lyman stated that he does not believe it is valid to simply add the increase in cladding oxidation that IRSN calculated for a particular scenario to Duke's own calculation for cladding oxidation, because, in his view, the proper way to do that calculation would be to actually use Duke's own time-temperature curves and modify the calculations for relocation effects. Tr. 2516-2517. Duke's witness stated that if he were to recalculate the total maximum cladding oxidation with his code (*i.e.*, the code used for Duke's licensing analysis), the impact would be around 10% or perhaps a little lower. Tr. at 2453. Dr. Meyer stated that 8 or 10% is a very reasonable number for the additional oxidation, and thus the IRSN number is reasonable based on his experience. Tr. at 2637-2638. Although the exact

[5] "Filling ratio," as discussed herein refers to the average density of accumulated fuel particles in the balloon, expressed as a percentage of the theoretical density of UO_2.

impact of relocation on the MOX fuel in Catawba may not be known, the Board finds that such a relocation penalty should not be applied to the cladding oxidation calculated with Appendix K models because these models already contain compensating conservatisms. *See* Tr. at 2312.

4.47. BREDL quotes IRSN's statements about the impact of fuel relocation in fuel rod balloons on the coolability of the blocked region. BREDL Proposed Findings at 21. We agree with IRSN that the impact of fuel relocation on heat transfer in partially blocked bundles has probably not been explored adequately. Ex. 36 at 23. However, this uncertainty would affect all fuel in all light-water reactors, and the only thing that would make it relevant to the MOX LTAs in Catawba would be a demonstrable difference in the amount of fuel relocation for MOX fuel and LEU fuel. While, as discussed in this opinion, there has been speculation about such differences, no evidence has been presented to demonstrate that such differences exist.

4.48. In its proposed findings, BREDL claims that MOX fuel may experience more severe relocation effects than LEU fuel at the same burnup because several characteristics that are important for relocation effects may be less favorable for MOX fuel. BREDL Proposed Findings at 12. According to BREDL, several characteristics of MOX fuel, including pellet fragment size and fuel-cladding interaction, may exacerbate relocation effects. *Id.* The Board finds that these claims, as discussed below, are not supported by the evidentiary record.

4.49. BREDL claims that smaller fuel pellet fragments will result in greater packing of the relocated area and hence higher filling ratios, although no evidence was provided to support this claim. Tr. at 2259. The Staff, however, testified that it is difficult to pack particles sufficiently to get high densities in a cylindrical geometry. Tr. at 2643.

4.50. Notwithstanding this testimony, BREDL attempted to show that there will be more small fuel particles in MOX fuel than in LEU fuel, proceeding on its assumption that smaller fragments would increase packing. BREDL claims that plutonium agglomerates that result from inhomogeneous fabrication of MOX fuel will result in more small particles being available for fuel relocation during a LOCA. *Id.* at 2260. The Staff pointed out that this fine-grained rim material also exists in LEU fuel and that there might be only a marginal (roughly 25%) increase in the amount of such material in MOX fuel compared with LEU fuel *Id.* at 2304. The Staff also testified that MOX fuel has more plasticity than LEU fuel, so that fewer particles that could participate in relocation would be expected. *Id.* at 2304, 2656.

4.51. BREDL also claims that thermal stresses during blowdown might be more severe in MOX fuel than in LEU fuel and thus result in more fuel fragmentation. *Id.* at 2260. But, the MOX LTAs are not located in peak power locations, so the fuel temperatures and hence thermal stresses during blowdown in the MOX fuel may not be greater than those in the LEU fuel, as assumed in BREDL's claim. *Id.* at 2123. Further, the greater plasticity of MOX fuel will oppose this effect. *Id.* Thus, the Board finds that BREDL has failed to establish that there would be any tendency for the MOX fuel in the LTAs to fragment more than the LEU fuel during blowdown.

4.52. During the hearing, there was some discussion about very small fuel particles, referred to as fines, being blown out of the burst opening when the fuel rod depressurizes, which implies that there would be few or no small particles in the ballooned region of the type that could make a difference in relocated fuel mass. *Id.* at 2304-05; BREDL Proposed Findings at 15. Dr. Lyman said that, because the tests in question were performed on BWR fuel rods and not PWR fuel rods, it is difficult to come to any conclusion about fine behavior in PWR fuel rods. Tr. at 2270. Dr. Meyer, however, successfully refuted this claim by pointing out that the BWR fuel pellets and the PWR fuel pellets are virtually identical, and that using a BWR fuel rod does not make any difference in terms of the behavior of material inside the cladding. Tr. at 2626.

4.53. BREDL further claimed that the absence of fine particles in the vicinity of the burst, as observed in these tests, does not provide evidence that fine particles escape from the fuel rod from locations throughout the entire fuel rod cross-section (in the case of MOX fuel). BREDL Proposed Findings at 16. Dr. Meyer, however, testified that distributed cracks open up throughout the fuel and there is no reason to believe that fine fuel particles would not be entrained in escaping gas throughout the volume of the fuel. Tr. at 2658.

Dr. Lyman also makes an issue of particles in the range of 0.3 millimeter (300 microns) in size that remained inside the balloon after the test. BREDL Proposed Findings at 16; Tr. at 2653. Dr. Meyer agreed that there were small particles remaining in the balloon, but that the smallest ones — the kind that would come from rim-type material in the 10-micron range — are probably all gone because those particles are almost aerosol size and would be easily entrained in the exiting gas. Tr. at 2654-2655.

4.54. Because BREDL has not presented any evidence to show there is greater fuel fragmentation for MOX fuel under LOCA conditions or that such an increase in fragmentation would lead to greater particle packing (*i.e.*, higher filling ratios) during fuel relocation, the Board finds that these claims amount to unsupported speculation by Dr. Lyman.

4.55. In addition to concern about pellet fragment size, BREDL expressed concern about differences in fuel-cladding bonding between MOX and LEU fuel and about the impact of such differences on fuel relocation during a LOCA. BREDL Proposed Findings at 17. BREDL postulates that bonding might be weaker in MOX fuel, in which case MOX fuel may have a greater propensity to earlier and more extensive fuel relocation than LEU. *Id.* The only basis given for this postulate was that MOX fuel is more resistant to cladding failures due to pellet-cladding mechanical interaction (PCM). Tr. at 2248. But the Staff pointed out, without contradiction, that there is no PCM during a LOCA and that the enhanced resistance to cladding failure of MOX fuel is the result of greater plasticity of MOX pellets and has nothing to do with bonding. *Id*. at 2313.

4.56. In relation to cladding swelling (*i.e.*, ballooning) during a LOCA, BREDL claims that the absence of an assessment as to whether the pellet-cladding bonding is weaker in MOX fuel than in LEU fuel results in not knowing the degree to which ignoring this effect is conservative for MOX fuel. BREDL Proposed Findings at 18. BREDL, however, is incorrect in its assumption that this issue has not been assessed. In this regard, the Staff provided recent data (Exhibit 40) that showed there is no apparent effect of bonding on balloon size and concluded that there would be no difference in ballooning between MOX fuel and LEU fuel. Tr. at 2302. We agree with the Staff.

4.57. BREDL expressed concern that irradiated fuel rods might experience greater cladding deformation (i.e., ballooning) than unirradiated fuel rods during a LOCA, based on an interpretation of results from the PB Power Burst Facility (Ex. 31 at 432-33). BREDL Proposed Findings at 18. BREDL then observed that the explanations of the PB results offered by Duke and the NRC Staff are not the same; thus, BREDL concluded that the phenomena are not well understood and that the possibility the results were due to irradiation effects cannot be ruled out. *Id.* The Staff, citing more recent and complete information than the other parties, provided a detailed explanation of the PB results that we find convincing, and thus we conclude that the behavior appears to be the result of well-known phenomena other than irradiation. Tr. at 2314-15. We note that even if the PB results were the result of irradiation, the variation in balloon sizes just discussed is not related to the use of MOX fuel pellets.

4.58. BREDL claims that the M5 cladding to be used in the MOX LTAs will balloon more during a LOCA than Zircaloy cladding and that larger balloons will result in a greater propensity for fuel relocation. BREDL Proposed Findings at 19. Dr. Lyman cites creep test results as the basis for this claim (Tr. at 2249), but, as Duke and the Staff testified, the large difference cited was a consequence of using inappropriate data (Duke Rebuttal Testimony at 17-18; Tr. at 2315).

4.59. BREDL further states that the ballooning size of M5 cladding remains unresolved because there is an absence of experimental data on the performance of high-burnup, M5-clad fuel, under LOCA conditions. BREDL Proposed Findings at 20. (The Board notes that there is also an absence of such data for Zircaloy-4 and ZIRLO, which are widely used, although ongoing research at Argonne National Laboratory is planned. Tr. at 2302; Ex. 35.) Nevertheless, a database exists on the performance of unirradiated M5 cladding under LOCA conditions, and the ballooning size from that database has been used for low-burnup and high-burnup fuel alike, because the ballooning size for unirradiated cladding will be greater than or equal to that for irradiated cladding (i.e., conservative) as a consequence of the embrittling effect of hydrogen which is picked up during normal operation. Tr. at 2159.

4.60. BREDL presents several arguments that are intended to show that the margin for peak cladding temperature and maximum oxidation in relation to the requirements in 10 CFR 50.46 are smaller for MOX fuel than for LEU fuel. BREDL Proposed Findings at 21-23. As discussed below, the Board finds that all of the arguments were adequately rebutted and disproved by the Staff and Duke.

4.61. The first argument makes reference to Duke's calculations comparing a MOX rod and an LEU rod in the same core position. Ex. 1 at 3-43. Duke, however, responded that they chose not to take credit for some differences between MOX fuel and LEU fuel that, in all likelihood, would reduce the MOX fuel peak cladding temperature below that of the LEU fuel. Tr. at 2222.

4.62. Next, BREDL asserts that the peak cladding temperature in a LOCA will be higher for a MOX fuel rod than for an LEU fuel rod because the linear heat generation rate for MOX fuel is generally higher than that for LEU fuel. *Id.* at 2251; BREDL Proposed Findings at 21-22. However, Duke points out that the MOX fuel LTAs at Catawba will operate at a linear heat generation rate that is lower than the peak for the LEU fuel in the same cycle of operation. Tr. at 2223. We note that this finding is also consistent with the Staff's opinion that, in reality, the peak cladding temperature for the MOX fuel should be a lower than that for the LEU fuel and that the margin for the MOX fuel will not be reduced. *Id.* at 2316.

4.63. Finally, BREDL argues that the balance of conservatisms and non-conservatisms, which applies when Appendix K models are applied for LEU fuel, is upset when Appendix K models are applied for MOX fuel without taking into account relocation, which may be more severe for MOX fuel than for LEU fuel. BREDL Proposed Findings at 23. As described in the above sections, there has been speculation about differences in relocation for MOX fuel and LEU fuel, but no evidence has been presented to demonstrate that such differences exist.

4.64. The Board finds BREDL's claim that the only way to fully and reasonably address the uncertainties associated with the behavior of high-burnup, M5-clad MOX fuel during LOCAs is to conduct integral tests of such fuel, (BREDL Proposed Findings at 24), to be unreasonable and to go well beyond current engineering practice. The Staff's arguments are persuasive: fuel performance during LOCAs is almost entirely controlled by cladding behavior, for which there is a substantial data base. Tr. at 2307. Further, we agree that the only fuel property that is different for MOX fuel in a significant way that would affect LOCA performance is the fuel thermal conductivity, and there is a substantial database for this as well. *See* Ex. 42. Integral testing of every combination of fuel pellet and cladding type is not a practical way of utilizing resources for safety research. Such integral testing might be beneficial if separate-effects tests showed a need, but such a showing of need has not been demonstrated in this hearing.

SUMMARY

4.65. It appears that all parties are in agreement that it is generally appropriate to apply the requirements of 10 CFR § 50.46 to MOX fuel. A question has been raised as to whether the effects of fuel relocation should be considered in Duke's Appendix K analysis for determining compliance with 10 CFR § 50.46. Based on our discussion above, we find no evidence that relocation would be worse for MOX fuel than for LEU fuel and thus conclude that Appendix K, as it has been applied for the Catawba MOX LTAs, is appropriate.

4.66. We agree that relocation effects in the ballooned region may be substantial. However, uncertainties associated with relocation effects are taken into account directly when realistic evaluation models are used in accordance with 10 CFR § 50.46(a)(1)(i) and indirectly, by compensating conservatisms, when Appendix K models are used in accordance with 10 CFR § 50.46(a)(1)(ii). Because no differences in relocation behavior have been demonstrated for MOX fuel and LEU fuel, we see no reason to depart from the current licensing practice in this regard.

4.67 We do not agree with BREDL's characterization that the MOX LTAs are novel fuel assemblies. *See* BREDL Proposed Findings at 26. MOX fuel has been irradiated in Big Rock Point, Dresden, San Onofre, Quad Cities, and Ginna Unit 1 in this country, and in more than 30 reactors in Europe. Tr. at 2113-15.

4.68. Finally, we note that BREDL made a major technical error at the beginning of this hearing which incorrectly suggested that relocation affected MOX fuel preferentially and that the impact on PCT was large. BREDL assumed that the temperature increase due to relocation should be added to the calculated peak cladding temperature, although the PCT generally does not occur in the balloon (Staff Testimony at 15). Once this error was corrected (compare BREDL Testimony at 10 to BREDL Rebuttal Testimony at 2), the remaining effects were found to be small in terms of a difference due to MOX fuel (Tr. at 2668) and of the effect of relocation itself on PCT (Tr. at 2636). This error apparently resulted from the lack of experience in this field of the BREDL witness (Tr. at 2455-2457),[6] and no persuasive evidence has been presented to show that remaining effects are anything but marginal at best.

Respectfully submitted,

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Dated at Rockville, Maryland
this 31st day of August, 2004

[6] We also note that at the outset of this matter, BREDL's expert made a technical error, that, in our opinion, reflects adversely on his expertise. Initially, BREDL misinterpreted an IPSN report, which actually stated that fuel relocation occurred at a temperature several hundred degrees lower for MOX fuel than for LEU fuel during a severe accident, by asserting that the phenomenon described occurred during a design basis LOCA. Although this error was based upon the French authors' misuse of one English word to describe the unrelated core-melt phenomenon, the error was not discovered by BREDL until pointed out by the Staff and Duke. (BREDL Second Supplemental Petition to Intervene at 3-4, Exhibit 28 at 6; Tr. at 644-46).

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(Catawba Nuclear Station	)	
Units 1 and 2)	)	

CERTIFICATE OF SERVICE

I hereby certify that copies of "NRC STAFF'S REPLY TO FINDINGS OF FACT AND CONCLUSIONS OF LAW CONCERNING BREDL CONTENTION I" in the above-captioned proceeding have been served on the following by deposit in the United States mail, first class; or as indicated by an asterisk (*), by deposit in the Nuclear Regulatory Commission's internal mail system; and by e-mail as indicated by a double asterisk (**), this 31st day of August, 2004.

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