

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)	)	

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

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August 6, 2004

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BACKGROUND

1.1. These findings and rulings address all outstanding issues with respect to the Blue Ridge Environmental Defense League's (BREDL) Contention I concerning Duke Energy Corporation's (Duke) license amendment request (LAR). The license amendment would permit the use of four mixed oxide (MOX) lead test assemblies (LTAs) in the core of either Unit 1 or Unit 2 at Duke's Catawba Nuclear Station.

1.2 Notice of the Nuclear Regulatory Commission's (NRC) receipt and consideration of the LAR was published in the *Federal Register* on July 25, 2003. 68 Fed. Reg. 44,107. The Notice advised the Applicant and any person whose interest may be affected by the proceeding of their right to request a hearing by filing such a request and a petition for leave to intervene. In response to the Notice, two petitions for leave to intervene were timely filed by BREDL and the Nuclear Information Resource Service (NIRS).

1.3 On September 17, 2003, an Atomic Safety and Licensing Board was established to rule on the petitions for hearing and leave to intervene and to preside over any adjudicatory proceeding that might be held in connection with the LAR. *Duke Energy Corp.* (McGuire Nuclear Station, Units 1 and 2; Catawba Nuclear Station, Units 1 and 2), ASLBP No. 03-815,

Docket Nos. 50-369-OLA, 50-370-OLA, 50-413-OLA, 50-414-OLA (2003). The petitioners timely filed 14 Contentions, which they sought to litigate in this proceeding. Blue Ridge Environmental Defense League's Supplemental Petition to Intervene (Oct. 24, 2003); Blue Ridge Environmental Defense League's Second Supplemental Petition to Intervene (Dec. 2, 2003).

1.4. On March 5, 2004, the Licensing Board issued its Memorandum and Order (Ruling on Standing and Contentions), in which the Board determined that BREDL and NIRS had demonstrated their standing to intervene in this matter, and that some of BREDL's contentions, in whole or in part, satisfied the Commission's requirements for admission as contested issues in this proceeding, but that NIRS had not submitted an admissible contention. *Duke Energy Corp.* (Catawba Nuclear Station, Units 1 and 2), LBP-04-04, 59 NRC 129 (2004). The Board admitted three restated and consolidated contentions. *Id.* Contention III was dismissed, on motion by Duke, as moot. Contention II was withdrawn by BREDL. Blue Ridge Environmental Defense League's Motion for Leave to Withdraw Contention II and Request to Change Hearing Schedule for Contention I (May 21, 2004); Order (Regarding Proposed Redacted Memorandum and Order, and Proposed Schedule Changes), ASLBP No. 03-815-03-OLA, Docket Nos. 50-413-OLA and 50-414-OLA (2004).

1.5. An evidentiary hearing with respect to BREDL Contention I was held in Rockville on July 14 - 15, 2004. Witnesses appeared on behalf of Duke, BREDL, and the Staff, as summarized below. In addition, limited appearance statements were received from members of the public, in a special session held in Charlotte, North Carolina on June 15, 2004.

1.6. These proposed findings of fact and conclusions of law present the Licensing Board's findings of fact with respect to the evidence presented in the July 2004 hearing concerning Contention I, and the Board's conclusions of law with respect thereto.

### APPLICABLE LEGAL STANDARDS

2.1. Commission regulations require that whenever a holder of a license wishes to amend the license or Technical Specifications an application for an amendment must be filed fully describing the changes desired. 10 C.F.R. § 50.90.

2.2. The regulations also provide for acceptance criteria for emergency core cooling systems (ECCS). The ECCS must be designed so that its “calculated cooling performance following postulated loss-of-coolant accidents” [LOCA] meets certain criteria. The criteria relevant to the contention in this proceeding are:

- The calculated maximum fuel element cladding temperature (Peak Cladding Temperature (PCT)) does not exceed 2200°F,
- The calculated total oxidation of the cladding does not exceed 17%,
- Calculated changes in core geometry shall maintain coolability.

10 C.F.R. § 50.46(b).

2.3 The regulation provides that an evaluation model must be used which either realistically describes the behavior of the reactor system during a LOCA such that the uncertainty in the calculated results can be estimated, or conforms with the required and acceptable features of 10 C.F.R. Part 50, Appendix K. Whichever approach to the evaluation model is followed, the results must meet the acceptance criteria stated in 10 C.F.R. 50.46(b). Specifically, the peak cladding temperature must not exceed 2200°F, the maximum local oxidation must not exceed 17%, the hydrogen generated must not exceed that which could be produced by oxidation of 1% of the total cladding, the core must remain in a coolable geometry, and the core temperature must remain at an acceptable level for an extended period of time. 10 C.F.R. § 50.46(b).

2.4. The PCT is the highest temperature calculated to occur in the reactor's core and is limited by 10 C.F.R. § 50.46 to 2200°F. The 2200°F limit on peak cladding temperature and the 17% limit on maximum local oxidation together assure that the cladding will not become embrittled

and lose its rod-like geometry during and after a LOCA.

### RULINGS ON PENDING MATTERS

3.1 Both the Staff and Duke objected to BREDL's proposed Exhibit C, "Status of NSC Activities in the Field of Fuel Behaviour," Nuclear Energy Agency/Nuclear Science Committee, NEA/NSC/DOC(2003)12 (May 2003). Tr. at 2487-88. The Staff objected based on the lateness of submission, extraneous material in the exhibit and redundancy. Letter from Susan L. Uttal to the Atomic Safety and Licensing Board (July 20, 2004). Duke submitted rebuttal testimony, per the Board's request, stating, *inter alia*, that Exhibit C "does not provide evidence of a difference in fuel pellet-cladding chemical interaction between MOX and LEU fuel," and that the exhibit "does not provide any evidence that, if such a difference actually existed, that it would matter under LOCA conditions." Supplemental Rebuttal Testimony of Steven P. Nesbit and J. Kevin McCoy on Behalf of Duke Energy Corporation on Contention I, July 20, 2004. Based on the cumulative nature of Exhibit C, the Board denies its admission.

### FINDINGS OF FACT

#### A. Background

4.1. The request to use the four MOX LTAs at Catawba is part of a non-proliferation program between the United States and Russia "to dispose of surplus plutonium from nuclear weapons by converting material into MOX fuel and using that fuel in nuclear power reactors." Tr. at 2111. "The current proposal for four MOX fuel lead assemblies supports the potential future use of larger quantities of MOX fuel at either Catawba or McGuire," which would require a separate licensing action. *Id.* "MOX fuel is essentially identical to LEU [low enriched uranium] fuel except that the MOX fuel pellets are comprised of a small amount of plutonium oxide mixed with the remainder uranium oxide." *Id.* at 2114. The MOX LTAs will be manufactured in France and will be based on the AREVA Advanced Mark-BW fuel assembly with some changes made to the fuel rod design to adapt the assembly for MOX fuel. *Id.* at 2112. The Advanced Mark-BW adaptation

for MOX applications uses M5 alloy fuel rod cladding, guide thimbles, and spacer grids. *Id.* Duke plans to insert the MOX LTAs into Catawba Unit 1 in Spring 2005. *Id.* The LTAs will be “irradiated for a minimum of two cycles to confirm acceptability of the fuel assembly design, verify the ability of Duke’s and AREVA’s models to predict fuel assembly performance, and confirm the applicability of the European database on MOX fuel performance to Duke’s use of MOX fuel.” *Id.* The core into which the MOX LTAs will be inserted will primarily consist of Westinghouse Robust Fuel Assembly fuel assemblies with eight Westinghouse Next Generation LTAs. *Id.*

4.2. As admitted by the Licensing Board, Contention I asserted:

The LAR is inadequate because Duke has failed to account for differences in MOX and LEU fuel behavior (both known differences and recent information on possible differences) and for the impact of such differences on LOCAs and on the DBA analysis for Catawba.

*Duke Energy Corp.* (Catawba Nuclear Station, Units 1 and 2), LBP-04-4, 59 NRC 129, 183 (2004).

4.3. The Licensing Board, in admitting this contention, noted that BREDL had provided “sufficient support from the IRSN [Institute for Radioprotection and Nuclear Safety (France)] . . . materials to render admissible its contention that Duke’s safety analysis is inadequate in the discussion of LOCAs.” LBP-04-4, 59 NRC at 166.

B. Testimony Presented

4.4. On July 1, 2004, prefiled testimony was filed by Duke, BREDL, and the Staff.

4.5. Duke’s prefiled testimony was presented by a panel consisting of Steven P. Nesbit, Robert C. Harvey, Bert M. Dunn and J. Kevin McCoy. “Testimony of Steven P. Nesbit, Robert C. Harvey, Bert M. Dunn and J. Kevin McCoy on Behalf of Duke Energy Corporation on Contention I (MOX Fuel Lead Assembly Program, MOX Fuel Characteristics and Behavior, and Design Basis Accident (LOCA) Analysis).” (Duke Testimony). Tr. at 2105. Mr. Nesbit is an Engineering Supervisor II employed by Duke and is the Duke Mixed Oxide Fuel Project Manager. *Id.* at 2107. He has 24 years of experience in nuclear engineering and management, with

particular experience in design engineering, nuclear safety analysis and nuclear reactor safety reviews. *Id.* Mr. Harvey is a Senior Engineer employed by Duke and is responsible for the LOCA analyses supporting the Oconee, McGuire and Catawba Nuclear Stations. *Id.* at 2108. He provided oversight to AREVA in the performance of supporting LOCA analyses for the MOX Fuel Program. *Id.* He has 25 years of experience in nuclear thermal hydraulic and safety analyses. *Id.* Mr. Dunn is an Advisory Engineer employed by AREVA Framatome ANP, Inc. and is responsible for the LOCA analyses supporting Duke's proposal to utilize four MOX LTAs at Catawba. *Id.* He has 34 years of experience in the nuclear engineering field, primarily in the area of LOCA analyses and safety analyses to support nuclear fuel design and licensing activities. *Id.* Dr. McCoy is an engineer with a Ph.D. in materials engineering and a masters degree in metallurgical engineering, and is employed by Framatome ANP, Inc. *Id.* He has 20 years experience in the nuclear industry, most recently in the area of MOX fuel performance. *Id.* The Board finds this panel well qualified to testify on the contents of the LAR, including the LOCA analysis and the differences in behavior between MOX and LEU fuel.

4.6. Duke's rebuttal testimony was presented by the same panel. "Rebuttal Testimony of Steven P. Nesbit, Robert C. Harvey, Bert M. Dunn and J. Kevin McCoy on Behalf of Duke Energy Corporation on Contention I." (Duke Rebuttal). Tr. at 2198.

4.7. Prefiled testimony on behalf of BREDL was provided by Dr. Edwin Lyman. "Prefiled Written Testimony of Dr. Edwin S. Lyman Regarding Contention I" (BREDL Testimony). Tr. at 2242. Dr. Lyman is employed by the Union of Concerned Scientists and has a Ph.D. in Physics. *Id.*; Ex. 25, Curriculum Vitae of Dr. Edwin S. Lyman. He has been studying issues related to the safety and security of MOX fuel for approximately 12 years and co-authored a paper relating to the possibility of using MOX fuel to dispose of separated plutonium. *Id.* at 2515. According to his testimony, he has conducted analyses of safety issues relating to the use of MOX fuel, including severe accident consequences, has attended numerous meetings, and has presented papers at



conferences. *Id.* Dr. Lyman has never developed a 10 C.F.R. Part 50, Appendix K LOCA evaluation model; never worked with a LOCA model computer code; never used computer codes to simulate fuel pellet performance or evolution; and never conducted experiments on fuel pellets or fuel rods. *Id.* at 2455-56. He does not have a degree in material science or materials engineering. *Id.* at 2456-57. His testimony was based on literature reviews of documents related to LOCA analysis. *Id.* at 2457. The Board finds that, by reason of his experience and training, Dr. Lyman's expertise relative to LOCA analysis and reactor fuel behavior is largely policy oriented. Although we will not find him ineligible to act as BREDL's expert in this area, we will assign his testimony appropriate weight commensurate with his expertise and qualifications. *See Carolina Power & Light Co.* (Shearon Harris Nuclear Power Plant), LBP-00-12, 51 NRC 247, 267, n. 9 (2000).

4.8. BREDL presented rebuttal testimony from Dr. Lyman. "Rebuttal Testimony of Dr. Edwin S. Lyman Regarding BREDL Contention I" (BREDL Rebuttal) Tr. at 2272.

4.9. Staff prefiled testimony was presented by a panel consisting of Undine Shoop, Dr. Ralph Landry and Dr. Ralph O. Meyer. "NRC Staff Testimony of Undine Shoop, Dr. Ralph Landry, and Dr. Ralph Meyer Concerning BREDL Contention I" (Staff Testimony) Tr. at 2291. Ms. Shoop is a Reactor Systems Engineer employed by the NRC. *Id.* She has a masters degree in Nuclear Engineering. Ex. 37, Professional Qualifications of Undine Shoop, Dr. Ralph Landry, and Dr. Ralph Meyer. She has experience in reviewing applications for the use of LTAs and requests for exemptions for the use of M5 cladding. *Id.*; Tr. at 2291-92. She has also reviewed new fuel designs. *Id.* She currently serves as the lead fuels reviewer for several projects involving technical evaluation of fuel designs, in-reactor fuel use, and core components. Tr. at 2291. This work includes reviewing new fuel designs, fuel transition methodologies, core component changes (such as control elements), fuel pellet modifications, fuel assembly component changes, and cladding material. *Id.* Dr. Landry is a Senior Reactor Engineer employed by the NRC. *Id.* He

has a Ph.D. in Nuclear Engineering. Ex. 37. He has 32 years experience as a nuclear engineer, 30 of them with the NRC. *Id.* He has experience in developing and running thermal hydraulic analysis codes specifically for containment analysis; reviewing LOCA codes and analyses; managing the LOFT and Semiscale LOCA experimental projects; managing the development of the RELAP5/MOD2 thermal hydraulic code; performing LOCA analyses for the NRC in support of regulation development; and serving as task leader for the review of all of the current state-of-the-art thermal hydraulic analysis codes. *Id.* His career has included all aspects of LOCA safety from code development to experimental data gathering to application of the codes to review of the industry's codes. *Id.* He is currently assigned responsibility for leadership in the reviews of the thermal hydraulic analysis computer codes. *Id.* This includes review of the advanced computing methodologies, Appendix K methodologies, advanced nuclear reactor system design analyses, and specific LOCA application analyses. Tr. at 2292. Dr. Meyer is a Senior Technical Advisor employed by the NRC. *Id.* His area of expertise is reactor fuel behavior. Ex. 37. He has a Ph.D. in Physics and has been working in the area of reactor fuel behavior for 36 years and has published over 40 journal articles and reports relating to nuclear reactor fuel. *Id.* He is currently responsible for the technical content of all of NRC's research on fuel behavior under conditions of design-basis accidents. Tr. at 2292. This work is currently being performed at three national laboratories and in six cooperative international programs. *Id.* The Board finds this panel well qualified to testify regarding LOCA analysis and differences in LEU and MOX fuel behavior.

4.10. Staff rebuttal testimony was presented by Dr. Landry and Dr. Meyer. "NRC Staff Rebuttal Testimony of Dr. Ralph Landry and Dr. Ralph Meyer Concerning BREDL Contention I" (Staff Rebuttal). Tr. at 2310.

C. Issues in Contention

4.11. In testimony on July 15, 2004, BREDL, through its expert, Dr. Lyman, limited the scope of the issues. Tr. at 2565-66. According to Dr. Lyman, Contention I "center[s] on the

absence of fuel relocation effects in Duke's calculations,"<sup>1</sup> Tr. at 2457; see also Tr. at 2604 (The "fundamental [issue] is that Duke used a deterministic appendix K model for calculating the 50.46 acceptance criteria that did not consider fuel relocation.") To a lesser extent, Dr. Lyman also believes that the difference in decay heat between LEU fuel and MOX fuel should be modeled in Appendix K. Tr. at 2565-66.<sup>2</sup>

Thus, the only issues to be resolved by this Board are 1) whether there are differences between LEU fuel and MOX fuel that affect relocation; and 2) whether the effects, if any, must be specifically accounted for by Duke to ensure compliance with 10 C.F.R. § 50.46.

#### D. LOCA Analysis

4.12. Appendix K to 10 C.F.R. Part 50 provides the descriptions of the required and acceptable features of the evaluation models as well as the required documentation. Tr. at 2295.

The first few paragraphs of Appendix K address matters related to fuel, such as how the decay heat is to be calculated, how stored energy is to be calculated, and how the heat from the reaction of the cladding material with the cooling water, or steam, is to be calculated. *Id.* at 2311. The remainder of the appendix gives specific details and requirements on how the heat removal by the coolant water is to be calculated, and how the movement of the coolant water through the reactor system is to be calculated. *Id.*

4.13. Pressurized water reactors like Catawba use circulating water to take heat from the

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<sup>1</sup> Fuel relocation during a LOCA refers to the movement of additional fuel pellet fragments into the ballooned region of a fuel rod.

<sup>2</sup> During cross-examination, however, Dr. Lyman conceded that "certain differences between MOX fuel and LEU fuel related to neutron power characteristics were modeled using LEU characteristics which are conservative for MOX." Tr. at 2457-58. He also agreed that Duke used LEU decay heat characteristics which are conservative for MOX fuel in a LOCA analysis. *Id.* at 2458. He is not challenging Duke's estimate that the decay heat conservatism can be up to 75°F. *Id.* Therefore, there are no issues in contention relating to the neutron power characteristics or decay heat.

fuel, and they generate steam with the hot water. Tr. at 2294. This removal of heat from the fuel keeps the fuel relatively cool in relation to temperatures that would cause fuel damage. *Id.* For a licensing analysis, it is assumed that a large pipe breaks and the water (i.e., the coolant) starts escaping when the reactor is at full power. *Id.* This loss of coolant automatically shuts down the reactor because the nuclear chain reaction cannot be sustained without the water, and power being produced by the fuel decays rapidly to very low levels. *Id.* After sufficient coolant has boiled away from the core region, the fuel cladding begins to heat up because heat is no longer being adequately removed from the cladding surface. *Id.* During the heatup, the cladding will soften, balloon, and burst because the internal pressure is high. *Id.* As the cladding continues to heat up beyond the temperature for bursting, the cladding begins to oxidize rapidly. *Id.* Eventually, cold water is injected into the core by an emergency core cooling system (ECCS) and the fuel cladding is cooled back down. Heat removal systems keep the reactor cool from that time on. *Id.*

4.14. Duke submitted a LOCA analysis as part of the LAR. Ex. 1. The ECCS performance of the Catawba nuclear plant is discussed in the analysis done for the current operating core. Tr. at 2294. That analysis was performed by Westinghouse using their NRC-approved realistic large-break loss-of-coolant accident analysis (LBLOCA) program, WCOBRA/TRAC. *Id.* The analysis of record demonstrates that the Catawba nuclear plant complies with the acceptance criteria delineated in 10 C.F.R. 50.46(b). *Id.* at 2294-95.

4.15. The Staff's review included a review of the analysis of record. Tr. at 2295; Ex. 39, Letter from M.S. Tuckman (Duke) to the NRC, "License Amendment to Request, Implementation of Best-Estimate Large Break Loss of Coolant Analysis Methodology," (August 10, 2000). The details of the review are found in the Staff's Safety Evaluation for Proposed Amendments to the Facility Operating License and Technical Specifications to Allow Insertion of Mixed Oxide Fuel Lead Assemblies (SE), sections 2.1.2 and 2.4.1, issued April 5, 2004. Ex. 38, "Safety Evaluation by the Office of Nuclear Reactor Regulation Renewed Facility Operating License NPF-35 and NPF-52"

(Apr. 5, 2004).

4.16. Duke evaluated the LOCA behavior of the proposed MOX LTAs in two ways. Tr. at 2296. First, the analysis of record was shown to still be valid for the Catawba nuclear plant with the Mark-BW/MOX1 assemblies (assembly structure used for MOX fuel) in the core. *Id.* This was done by comparison of the hydraulic behavior of the Mark-BW/MOX1 assembly with the Westinghouse RFA assembly and the Framatome Mark-BW (LEU) assembly used in the mixed-core study in the analysis of record. *Id.* The comparison shows that the Mark-BW/MOX1 assembly is much closer in hydraulic behavior to the Westinghouse RFA fuel than is the Mark-BW fuel design and is therefore bounded by the study. *Id.*; Ex. 2, Response to Request for Additional Information, section 3.7.1.7 (Nov. 3, 2003).

The second evaluation performed was a large-break LOCA analysis of the MOX fuel assembly itself. Tr. at 2296. Framatome ANP performed that analysis using their NRC-approved 10 C.F.R. Part 50, Appendix K computer code, RELAP5/MOD2-B&W. *Id.* at 2297. Framatome ANP also analyzed the MOX-type assembly loaded with LEU fuel rather than the MOX fuel, thus obtaining a comparison for MOX versus LEU fuel when installed in the same core location. *Id.* The results of those studies are that the peak cladding temperature for the MOX fuel is 2018°F,<sup>3</sup> while that of the same fuel assembly design containing LEU fuel is 1981°F. *Id.*; Ex. 1, Table 3-5.

4.17. The analysis of record for Catawba states that the peak cladding temperature for the resident LEU fuel is 2056°F. Tr. at 2648. The value of 2019.5°F is the value of the peak cladding temperature obtained from analysis of the MOX LTA under the conditions they will see in operation in Catawba. *Id.* The Staff reviewed the analysis of the MOX LTAs and agreed that the peak cladding temperature was approximately 2020°F, which is below the peak cladding temperature of the resident fuel. *Id.*

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<sup>3</sup> On November 3, 2003, Duke submitted an answer to a Staff question that corrected the peak cladding temperature to 2019.5°F. Tr. at 2646; Ex. 2 at 31.

4.18. The requirements specified in 10 C.F.R. Part 50, Appendix K for an acceptable evaluation model are not dependent upon the content of the fuel pellet except in limited areas: initial stored energy, decay heat, and fission heat. Tr. at 2297.

4.19. The fuel stored energy, which is a measure of the initial temperature of the fuel, was calculated by Framatome ANP using their NRC-approved COPERNIC fuel code, which has been modified and approved to include MOX properties. Ex. 1; Tr. at 2297. COPERNIC supplies the stored energy and thermal conductivity values to the LOCA code; therefore, MOX-specific parameters were used in the analysis and the results account for the differences between LEU and MOX fuel in the stored energy and thermal conductivity calculations. Tr. at 2300.

4.20. The rate at which the fuel continues to produce heat after the nuclear reaction has been shut down is determined by the decay heat model. Tr. at 2297. The applicability of the Framatome ANP decay heat model to MOX fuel was reviewed by the staff. *Id.* The requirement of Appendix K, 10 C.F.R. 50, Appendix K 1.A.4, is that the ANSI/ANS-5.1-1971 decay heat curve must be multiplied by 1.2 and then used to predict the heat generation by uranium dioxide fuel following cessation of the nuclear chain reaction. *Id.* Duke stated in the LAR, Section 3.7.1.1.2, that Framatome ANP utilized a decay heat curve that bounded the Appendix K requirement and also bounded the ANSI/ANS-5.1-1994 standard. *Id.*; Ex.45, American National Standard for Decay Heat Power in Light Water Reactors, ANSI/ANS-5.1-1994, American Nuclear Society (1994). ANSI/ANS-5.1-1994 accounts for the fact that for long exposure times, LEU fuel produces the majority of its energy from the fission of plutonium. Tr. at 2297. Therefore, the 1994 standard is the more appropriate model to use for the decay heat production of MOX fuel than the 1971 model. *Id.* at 2297-98. The resulting decay heat curve used by Framatome ANP is thus conservative with respect to the decay heat generated by the MOX fuel as well as being more conservative than the model specified in Appendix K. *Id.* at 2298.

4.21. As specified by Appendix K, fission heat was calculated based on the known

reactivity of the fuel and the effects on reactivity that occur during a LOCA. Tr. at 2298. Both factors are well understood for LEU and MOX fuel. *Id.* Each of these factors was assumed to be at its worst value: that is, the fission heat was maximized as required. *Id.*

4.22. In summary, Duke accounted for the effect of MOX on the LOCA through use of an approved MOX-applicable method of determining the fuel stored energy at the initiation of the LOCA and use of a conservative MOX-applicable decay heat model and fission heat model to determine the heat production of the fuel during the LOCA analysis. Use of these sources of heat ensure a conservative prediction of the behavior of the MOX LTAs in the unlikely event of a LOCA. The parameters provided by the fuel performance code to the LOCA analysis in the LAR are also MOX-specific parameters, so the differences introduced from the use of MOX on the LOCA calculation are accounted for in the analysis. Thus, the LAR accounts for differences between MOX and LEU fuel behavior and the potential impact of such differences on LOCAs.

4.23. Although NRC regulations at 10 C.F.R. Part 50, Appendix K do not require an accounting of the effects of fuel relocation into the ballooned portion of a fuel rod during a LOCA, the hearing nevertheless focused on these effects because relocation was the area of concern raised by BREDL. See paragraph 4.11, *supra*. The closely related subjects of cladding ballooning, fuel relocation, and cladding oxidation are therefore discussed in more detail in the following paragraphs.

Appendix K has been in effect since 1974, and over the years some extra conservatisms and some non-conservatisms have been identified. *Id.* at 2312. The Appendix K model does not account for relocation, which has a non-conservative impact, but it does not take credit for other known extra conservative factors, either. *Id.* at 2669-70. In order to make a licensing calculation using Appendix K, nothing needs to be added to it to account for fuel relocation because it has compensating conservatisms. *Id.* at 2670-71. Further, Duke's model adequately accounted for any non-conservatisms. *Id.* at 2312.

E. Cladding Ballooning

4.24. The review of M5 cladding was done several years ago. Tr. at 2301. Nothing that has been learned since that time has invalidated the Staff's overall conclusion that M5 is an acceptable cladding material. *Id.* at 2301-02.

4.25. Fuel rods are pressurized with helium during fabrication and further with fission gas during operation, and at normal full-power operation the internal rod pressure is high. Tr. at 2302. Near the end of the fuel lifetime, the pressure on the inside is roughly balanced by the pressure on the outside (i.e., the reactor system pressure). *Id.* When the coolant is lost in a LOCA, the system pressure is also lost, so the resulting large fuel rod pressure differential tries to expand the cladding. *Id.* When the cladding temperature reaches 600° to 700°C (approximately 1100° to 1300°F), cladding expansion becomes rapid, and around 800°C (approximately 1500°F) the fuel rod bursts just like a rubber balloon would burst. *Id.* The fuel rod's internal pressure is then lost, and the deformation or ballooning ceases. *Id.*

4.26. The diameter increase at the ballooned location can be as big as 100%, but it is usually smaller. Tr. at 2630, 2632. One hundred percent would not be appropriate for Catawba. *Id.* at 2639. The maximum strains (balloons) are only about 50 percent for Catawba. Tr. 2640, 2128 ¶ 56, 2159 ¶ 111.

4.27. There is no effect of pellet-to-cladding bonding on the size of the balloon. It had been postulated by the Staff that bonding between the pellet and the cladding was going to have a significant effect on the balloon size, because bonding is quite severe at high burnup. Tr. at 2628. However, testing was performed at Argonne National Laboratory that demonstrated that pellet-cladding bonding does not affect the balloon size. Tr. at 2628; Ex. 40, Y. Yan, et al., "LOCA Test Results for High-Burnup BWR Fuel and Cladding," Organization for Economic Cooperation and Development (OECD) Topical Meeting on LOCA Issues, p. 17 (May 25-26, 2004). The LOCA conditions apparently snap the bond between the pellet and the cladding when the outward



deformation starts developing as the temperature rises. Tr. at 2641-42. Because there is no effect of bonding on the size of the balloon, there can be no difference in the size of the balloon as a consequence of any difference in the degree of bonding between LEU and MOX fuel. *Id.* at 2642.

4.28. In his pre-filed testimony, Dr. Lyman asserted that LOCA test results from the Power Burst Facility (PBF) demonstrated that irradiated rods experience greater deformation (swelling) than unirradiated rods. Tr. at 2261. But, after the PBF tests were performed, more work was done on the effects of temperature uniformity at the Karlsruhe nuclear research center in Germany by F.J. Erbacher and others. *Id.* at 2314. The Staff's rebuttal testimony explains that Dr. Lyman's assertion is incorrect because there is no systematic difference between fresh fuel and irradiated rods in the tests that have been cited. *Id.* at 2314-15. The variation in balloon sizes just discussed is not related to the use of MOX fuel pellets. *Id.*

4.29. The diameter of the balloon will be about the same whether the cladding is M5 or Zircaloy. See Ex. 41, N. Waeckel et al., "Does M5 Balloon More than Zircaloy-4 Under LOCA Conditions?," OECD Topical Meeting on LOCA Issues, p. 10 (May 25-26, 2004). Dr. Lyman claims that this recent presentation by N. Waeckel does not fully address the differences in size of balloons between M5 and Zircaloy cladding. Tr. at 2262. The Staff addressed this claim in its rebuttal testimony (*Id.* at 2315) and concluded that the M5 ballooning size is virtually the same as for Zircaloy. *Id.* at 2630.

4.30. Fuel rods are approximately 12-feet long. Tr. at 2306; Ex. 1 at 3-40. Because of local temperature variations, a localized bulge or balloon develops in a fuel rod under LOCA conditions and then ruptures. Tr. at 2306. These ruptured balloons are only a few inches long. *Id.* Only about 3 inches of the 12-foot long fuel rod are threatened by embrittlement during a LOCA. *Id.*

4.31. Ballooning is a cladding issue; it is not a MOX issue. Tr. at 2315. Therefore, there is no valid reason to expect that the size of the balloons will be affected by the type of fuel inside

the fuel rods. *Id.* The balloon size has been adequately accounted for in Duke's analysis. *Id.*

F. Fuel Relocation

4.32. After ballooning occurs during a LOCA, fuel material can move around inside the fuel rod. Tr. at 2303. Fuel pellets, which are about the size of little marshmallows, develop cracks during normal operation such that they can easily break apart. *Id.* Tests have shown that broken pieces of fuel pellets can move down into the ballooned region of the cladding. *Id.*

If extra fuel particles or fragments move into the ballooned region, they would increase the mass of fuel in that region and thereby increase the heat generated in that region. *Id.* at 2304. The increased heat generation would increase the cladding temperature in the balloon and thus increase the amount of cladding oxidation, which causes embrittlement. *Id.*

It has been claimed by BREDL that the amount of relocated material, characterized as a filling ratio or packing fraction, is a function of the average particle size of the fuel fragments, and that smaller particles will result in more fuel in the ballooned area. Tr. at 2259.

4.33. Dr. Lyman referred to MOX and LEU microstructures from the Cabri program in France and the Argonne program in the United States. Tr. at 2467-69, 2470-73. He then concluded that there would be more fine particles in MOX fuel than in LEU fuel. Duke's witnesses did not agree with this interpretation. *Id.* at 2525-26. The Staff's witness, Dr. Meyer, pointed out that there is probably a little more rim (fine grained) material in MOX fuel, but that the additional amount would be limited to roughly 25%. *Id.* at 2304. No testimony was offered to demonstrate that an increase in the amount of small particles would necessarily increase the average density, and, in fact, it was stated that it is very difficult to pack particles together to get a high density. *Id.* at 2642. Therefore, even if the particle size is smaller in MOX fuel than in LEU fuel, BREDL did not offer any evidence to show that one could increase the packing fraction above what has already been assumed in the parametric study done by IRSN. *Id.* at 2643.

4.34. Any increase in the amount of fine fuel particles between MOX and LEU fuel fragments once the cladding balloons would probably not matter. Tr. at 2304. In recent high-burnup integral tests at Argonne National Laboratory, black deposits have been observed on the quartz tube of the apparatus just opposite the burst opening. *Id.* Large fuel fragments are also visible through the burst opening, and these particles have no small particles or fines around them. *Id.* at 2304-05; Ex. 40 at 17. It thus appears that the small particles, or fines, are blown out of the burst opening when the rod depressurizes. Tr. at 2305. Therefore, there would be few or no small particles in the ballooned region, and it is these small particles that have been postulated to make a difference between the mass of fuel in the balloon in MOX fuel and LEU fuel. *Id.* at 2654-65.

4.35. For the Catawba plant, the heat source in the balloon for MOX fuel would actually be less than it would be for LEU fuel. For this plant, the peak cladding temperature occurs a couple of minutes after the loss of coolant has shut down the power. Tr. at 2305. By that time, most of the stored heat in the fuel has been dissipated and the chemical heat from the metal-water reaction is small, so the heat source is dominated by decay heat. *Id.* Decay heat for MOX fuel is lower than it is for LEU fuel at the time the MOX peak cladding temperature occurs. *Id.* Therefore, the total heat source in the balloon will be lower for MOX fuel than for LEU fuel.

4.36. If fuel relocation has any effect (for LEU fuel or MOX fuel), it would increase the temperature only in the ballooned region of the fuel rod. Tr. at 2305. Because of the larger surface area of the ballooned region, its cooling is enhanced, and, therefore, the ballooned region is seldom the location of the calculated peak cladding temperature when relocation is ignored. *Id.* For the MOX fuel in Catawba, Duke calculated a maximum cladding temperature in the balloon of only 1750°F (*Id.* at 2500). The Duke calculation did not include the effects of relocation, but the effects can be estimated by adding the temperature increment found in the parametric studies of the

relocation effect. Hence, if 270°F<sup>4</sup> is added to the maximum cladding temperature of 1750°F in the balloon, the result is the highest expected temperature in the balloon of 2020°F. Tr. at 2635-36. This bounding increase in peak cladding temperature is almost identical to the peak cladding temperature of 2018°F reported by Duke and would still be well below the allowable temperature of 2200°F. Experimental results from the FR2 in-reactor tests, cited by the Staff, show a slightly lower maximum temperature in the balloon than at the peak temperature location for the test with fuel relocation. Tr. at 2636. This experimental result is entirely consistent with the above conclusion based on a parametric study.

4.37. The relocation effect is an important effect, but there is no demonstrated difference between MOX fuel and LEU fuel as to relocation. Tr. at 2682-83.

G. Cladding Oxidation

4.38. If extra fuel particles or fragments move into the ballooned region, they will increase the mass of fuel in that region and thereby increase the heat generated in that region. Tr. at 2304. The increased heat generation would increase the cladding temperature in the balloon and thus increase the amount of cladding oxidation, which causes embrittlement. *Id.*

4.39. The increase in the amount of oxidation was estimated by IRSN in their parametric study to be about 10 percent. *Id.* at 2684. This is a significant increase, but when added to the 3%<sup>5</sup> reported by Catawba (Tr. 2175 ¶ 154), the total is still less than the 17% licensing limit.

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<sup>4</sup> That temperature, 270°F, is the largest value in IRSN's recent parametric study (Ex. 30, V. Guillard, et al., "Use of Cathare 2 Reactor Calculations to anticipate Research Needs, "SEGFSM Topical Meeting on LOCA Issues, Argonne National Laboratory (May 2004)).

<sup>5</sup> At the hearing on July 15, 2004, the Staff incorrectly stated that oxidation in the Duke analysis without relocation was higher in the ballooned region than at the location of the peak cladding temperature (Tr. 2306, 2636, 2684, 2686). The error does not affect the conclusion that oxidation at the ballooned region would be within the regulatory limit.

H. Summary

4.40. There is no indication — only speculation — that the effects of fuel relocation will be any different for MOX fuel than for LEU fuel in Catawba. Although there are uncertainties with fuel relocation, they are bounded. Tr. at 2697-98. The NRC has a practice of identifying and investigating uncertainties. *Id.* But the presence of uncertainties does not require licensing action unless the Staff can no longer conclude that reasonable assurance exists that the public health and safety will be protected. *Id.* Such evidence is not present in this case. *Id.*

4.41. There is sufficient data regarding MOX fuel performance during LOCAs for the staff to make a finding of reasonable assurance that the public health and safety will be protected if the license amendment is approved. Tr. at 2293. Fuel performance during LOCAs is almost entirely controlled by cladding behavior, which is unaffected by fuel type. *Id.* at 2307. Thus the database for cladding behavior is the same for MOX fuel and for LEU fuel, and it is substantial. *Id.* The use of MOX fuel pellets will have a small effect on fuel temperatures. *Id.* The most critical measurements in relation to fuel temperatures and LOCA behavior are direct measurements of centerline temperature such as those taken in the Halden test reactor, which have provided an adequate database for validation of fuel rod codes for application to MOX fuel at high burnup. *Id.*; Ex. 42, Memorandum from Farouk Eltawila, RES, to Suzanne C. Black, NRR, RE: Response to User Need for Development of Radiological Source Terms for Review of Mixed Oxide Fuel Lead Test Assemblies, Attachment B, Figure 1 (February 23, 2004).

4.42. In summary, Duke submitted analyses, calculations and modeling results that demonstrate that the MOX LTAs would remain within the regulatory limits under LOCA conditions as required by 10 C.F.R. § 50.46. Specifically, Duke's submission demonstrates that cladding oxidation would not exceed 17%, peak cladding temperature would not exceed 2200°F, and core coolability would be maintained. The calculations and conclusions were examined by the Staff and found to be acceptable. In contrast, Dr. Lyman performed no analyses, produced no models, and

provided no calculations to demonstrate that the LAR is inadequate. Dr. Lyman postulated that relocation would be a greater problem with MOX fuel, but he never satisfactorily demonstrated that his conclusion was more than mere speculation. He produced no evidence that would demonstrate that consideration of relocation is necessary or that it would have any effect on the Staff's conclusion that use of the four MOX LTAs would not adversely affect public health and safety. Expert testimony by the Staff refuted Dr. Lyman's conclusion. We find the Staff's testimony to be more persuasive, better founded in fact and based on greater expertise. In sum, we find that BREDL has not demonstrated that:

- a. the effects of relocation would be different for MOX;
- b. cladding balloon size would be larger because of the use of MOX and M5 cladding;
- c. there are any demonstrable differences between MOX and LEU that would render Duke's analyses invalid or non-conservative.

#### CONCLUSIONS OF LAW

5.1 The Licensing Board has considered all the evidence presented by the parties on Contention I. Based upon a review of the entire record in this proceeding and the proposed findings of fact and conclusions of law submitted by the parties, and based upon the findings of fact set forth above, which are supported by reliable, probative and substantial evidence in the record, the Board has decided all matters in controversy concerning this contention and reaches the following conclusions.

5.2. A contention must contain "a genuine dispute . . . on a material issue of law or fact." 10 C.F.R. § 2.714(b)(iii). The fact that there may be research underway in an area does not, in itself, create a genuine dispute on a material issue of fact. See *Pennsylvania Power & Light Co.* (Susquehanna Steam Electric Station, Units 1 and 2), LBP-79-6, 9 NRC 291, 325 (1979); see also *Georgia Power Co.* (Vogtle Electric Generating Plant, Units 1 and 2), LBP-86-41, 24 NRC 901, 927 (1986). In the instant case, BREDL has offered reports of ongoing research by international

and American research organizations as evidence that the LAR is inadequate. To the extent that BREDL relies on ongoing research, the Board finds that BREDL has not proven that a genuine dispute on a material issue of law or fact exists.

5.3. The use of MOX fuel does have an impact on the ECCS calculations. However, these impacts have been accounted for and will be well within the licensing limits. Tr. at 2684. Therefore, the Board finds that Duke has shown public health and safety will be adequately protected if the MOX LTAs are irradiated at Catawba.

Respectfully submitted,

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Dated this 6<sup>th</sup> day of August, 2004  
in Rockville, Maryland

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 )

CERTIFICATE OF SERVICE

I hereby certify that copies of "NRC STAFF'S PROPOSED 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 6<sup>TH</sup> day of August, 2004.

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