

July 1, 2004

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))	

**PREFILED WRITTEN TESTIMONY OF
DR. EDWIN S. LYMAN
REGARDING CONTENTION I**

On behalf of Blue Ridge Environmental Defense League (“BREDL”), Dr. Edwin S.

Lyman hereby submits the following testimony regarding BREDL’s Contention I.

Q.1. Please state your name and describe your professional qualifications to give this testimony.

A.1. My name is Dr. Edwin S. Lyman. I am a Senior Scientist with the Global Security Program at the Union of Concerned Scientists, 1707 H Street, NW, Suite 600, Washington, D.C. 20006. My education and experience are described in my curriculum vita, which is attached to my testimony as **Exhibit A**.

I am a qualified expert on nuclear safety and safeguards issues. I hold a Ph.D., a master of science degree, and a bachelor’s degree in physics. For over eleven years, I have conducted research on security and environmental issues associated with the management of nuclear materials and the operation of nuclear power plants. My research has included the safety and security implications of using mixed oxide fuel as a substitute for uranium fuel in nuclear power plants. I have also published articles on this topic. A list of my publications is included in my C.V.

Q.2. What is the purpose of your testimony?

A.2. The purpose of my testimony is to discuss my views on BREDL Contention I, which was admitted for litigation by the Atomic Safety and Licensing Board (“ASLB”) in LBP-04-04, Memorandum and Order (Ruling on Standing and Contentions) (March 5, 2004). BREDL Contention I asserts that Duke Energy Corporation’s (“Duke’s”) license amendment request

(“LAR”) to test plutonium mixed oxide (“MOX”) fuel at the Catawba nuclear power plant is inadequate because Duke has failed to account for the differences between MOX and low enriched uranium (“LEU”) fuel behavior; nor has Duke accounted for the impact of these differences on Duke’s analysis of loss of coolant accidents (“LOCAs”).

Q.3. What materials have you reviewed in preparation for your testimony?

A.3. I have reviewed Duke’s LAR and related correspondence, including Duke’s responses to Requests for Additional Information (“RAIs”) by the NRC Staff. I have also reviewed the body of literature which has been developed regarding the behavior of MOX and other types of reactor fuel under LOCA conditions. I am also familiar with relevant NRC documents, including correspondence regarding this license amendment application, reports and correspondence concerning characteristics and behavior of MOX fuel, and correspondence and reports concerning the behavior of LEU fuel under LOCA conditions. In addition, I am familiar with regulations and guidance of the U.S. Nuclear Regulatory Commission (“NRC”) and the U.S. Department of Energy (“DOE”) governing plutonium processing facilities. Finally, I am familiar with U.S. and foreign government reports regarding testing of LEU fuel under accident conditions.

Q.4. Please summarize the conclusions you have reached regarding the adequacy of Duke’s LAR application to account for the differences between MOX and LEU fuel.

A.4. In my professional judgment, Duke’s design-basis loss of coolant (“DB-LOCA”) analysis is inadequate because it does not address the uncertainties associated with relocation effects that M5-clad MOX fuel may experience under LOCA conditions. These uncertainties relate to Duke’s assertion that the action proposed in the MOX LTA LAR will not result in a violation of the emergency core cooling system (ECCS) acceptance criteria in 10 C.F.R. § 50.46: peak cladding temperature (“PCT”), maximum cladding oxidation, and the preservation of a coolable core geometry.

The phenomenon of fuel relocation has been observed in experiments with irradiated LEU fuel under LOCA conditions. While to my knowledge no similar experiments have been done on MOX fuel, there are technical reasons to believe that the impact of fuel relocation effects during a LOCA may be more severe for MOX fuel rods than for LEU fuel rods of the same burnup, due to differences in characteristics such as fuel fragment sizes and fuel-clad interactions. Moreover, calculations in Duke’s LAR indicate that MOX fuel is generally more limiting than LEU fuel with respect to DB-LOCAs. Therefore, the consequences of fuel relocation, and the non-conservatism associated with neglecting them, may be of greater concern for MOX fuel rods than for LEU fuel rods with respect to compliance with LOCA regulatory criteria.

Duke has failed to address these uncertainties in MOX fuel behavior, and therefore its LTA application is unacceptable to satisfy the requirements of 10 C.F.R. § 50.46 with respect to PCT, maximum cladding oxidation, and coolable geometry of fuel. In addition, by failing to address the uncertainties in MOX fuel behavior, Duke has not demonstrated compliance with the general reasonable assurance standard in 10 C.F.R. § 50.40(a).

I do not believe, however, that these uncertainties can be addressed with mere calculations or analyses based on LEU performance. In my professional opinion, the only satisfactory way to address these uncertainties would be to conduct integral tests of MOX fuel assemblies under LOCA conditions in such a manner that the impacts of the phenomena I have previously described can be measured with reasonable accuracy and precision.

Q 5: Please explain how the regulations in 10 C.F.R. § 50.46 apply to Contention I.

A.5: NRC regulations at 10 C.F.R. § 50.46 establish acceptance criteria for emergency core cooling systems for light-water nuclear reactors. Essentially, the regulation sets design limits for behavior of the reactor fuel under LOCA conditions. Appendix K to Part 50, whose requirements are referenced in 10 C.F.R. § 50.46(a)(1), sets forth ECCS “evaluation models,” *i.e.*, assumptions about the behavior of reactor fuel that are to be used in determining whether it complies with the criteria in 10 C.F.R. § 50.46.

10 C.F.R. § 50.46 and Appendix K apply only to uranium-based fuel, but Duke has requested an exemption from this limitation so that these requirements will apply to MOX fuel. I believe that it is generally appropriate to apply the requirements of 10 C.F.R. § 50.46 to MOX fuel, as long as Appendix K is not strictly applied to exclude consideration of relocation of the fuel during LOCAs.

The regulations in 10 C.F.R. § 50.46 sets forth fuel performance limits in three categories that have importance with respect to performance of MOX fuel: peak cladding temperature (“PCT”), maximum cladding oxidation, and coolable geometry. Section 50.46(b)(1) requires that that PCT “shall not exceed 2200° F.” Section 50.46(b)(2) provides that the “calculated total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation.” Section 50.46(b)(4) also requires that “[c]alculated changes in core geometry shall be such that the core remains amenable to cooling.”

Q.6: Please explain why you think the Appendix K evaluation models for the MOX LTA core should include consideration of fuel relocation during LOCAs.

A.6: Appendix K does not include consideration of fuel relocation. The NRC did contemplate including fuel relocation as a criterion in Appendix K, but claimed to have resolved the question in Generic Issue 92. Memorandum from Ralph Meyer, NRC Office of Nuclear Regulatory Research, to John Flack, NRC Regulatory Effectiveness and Human Factors Branch, re: Update on Generic Issue 92, Fuel Crumbling During LOCA (February 8, 2001) (NRC ACN # ML010390163) (hereinafter “Meyer Memorandum”). A copy is attached to my testimony as **Exhibit B**. *See also* Memorandum from Ashok C. Thadani, Office of Nuclear Regulatory Research, to Samuel J. Collins, Office of Nuclear Reactor Regulation, re: Information Letter 0202, Revision of 10 CFR 50.46 and Appendix K (June 20, 2002) (hereinafter “Thadani Memorandum”) (NRC ACN # ML 021720690). A copy is attached to my testimony as **Exhibit C**. More recently, the NRC has acknowledged that omission of fuel relocation effects is a non-conservatism in Appendix K with a very large potential impact on PCT, and that an early “resolution” of this issue (*i.e.*, Generic Issue 92) may have been in error or is no longer

applicable because of new information. *See*; Meyer Memorandum and Thadani Memorandum, Attachment 4 at 4-5.

As I will discuss in more detail later in my testimony, certain characteristics of MOX fuel appear to exacerbate the effects of fuel relocation, thus leading to higher PCTs and greater maximum cladding oxidation. While there are several other known non-conservatisms in Appendix K, this one in particular appears to be relevant to the MOX LTA LAR because of its disproportionately large impact on the MOX LTAs compared to the LEU assemblies that comprise the remainder of the core. Given the potential impact on PCT of relocation effects, it is not appropriate to omit consideration of this phenomenon from the Appendix K models that Duke uses to establish that loading of the MOX LTAs into Catawba will result in compliance with 10 CFR § 50.46 criteria.

Q.7: Please explain what you mean by fuel relocation during a LOCA.

A.7: According to NRC, “fuel relocation refers to the movement of fuel pellet fragments into regions of the fuel rod where the cladding has ballooned during a LOCA transient.” Thadani Memorandum, Attachment 4 at 4-5.

Q.8: Please explain why fuel relocation could increase the severity of a LOCA.

A.8: Fuel relocation increases the local linear heat generation rate within the ballooned area. Thus it could increase the severity of a LOCA by resulting in a greater fuel rod peak cladding temperature (PCT) than in a situation in which fuel relocation did not occur. Because transient oxidation during a LOCA increases with an increase in PCT, fuel relocation could also result in a greater maximum cladding oxidation. Finally, the greater local linear heat generation rate requires a greater coolant flow around the ballooned area to ensure long-term core coolability. *See* slides presented by A. Mailliat and J.C. Mélis, IRSN, at “PHEBUS STLOC Meeting” with NRC Staff (October 23, 2003) (NRC ACN # ML032970624) (hereinafter October 2003 IRSN Presentation”). A copy is attached to my testimony as **Exhibit D**.

Q.9: Please discuss the potential magnitude of the impact of fuel relocation on PCT and maximum cladding oxidation for uranium oxide (UO₂) fuel.

A.9: The most recent calculations of the impact of fuel relocation on PCT of which I am aware were conducted by the Institut de Protection et de Sûreté Nucléaire (IPSN, now IRSN) and published in 2001. In that study, the authors used the CATHARE2 computer code to calculate the impact of fuel relocation on the large-break LOCA PCT for a high-burnup UO₂ fuel rod as a function of the “filling ratio,” or the ratio of the volume of the relocated fuel material to the volume of the ballooned region. For the scenario evaluated, the authors found that the PCT in the absence of relocation effects was 970°C. For a filling ratio of 70%, the maximum considered, the PCT was 1144°C. For a filling ratio of 40%, the PCT was about 20°C greater than for the no-relocation case. Thus the maximum impact on PCT of relocation in this study was a ΔPCT of +174°C (313°F) for high-burnup UO₂ fuel. It is not clear from the study whether higher filling ratios, and hence larger impacts on PCT, are possible. C. Grandjean, G. Hache and C. Rongier, “High Burnup UO₂ Fuel LOCA Calculations to Evaluate the Possible Impact of Fuel Relocation After Burst,” OECD/NEA Proceedings of the Topical Meeting on LOCA Fuel Safety Criteria, Aix-en-

Provence (March 22-23, 2001) (hereinafter “Grandjean, Hache, and Rongier”). A copy of this paper is attached to my testimony as **Exhibit E**. The NRC staff appears to be familiar with this result. See Thadani Memorandum, Attachment 5 at 4.

The study also evaluated the impact on the maximum cladding oxidation for the ruptured region (two-sided oxidation). The equivalent cladding reacted (ECR) calculated by the Cathcart-Pawel rate law (a surrogate for “maximum cladding oxidation”) was 12.6% for the no-relocation case, and 19.7% for the 70% filling ratio case. Thus the maximum impact on ECR resulting from relocation was calculated as $\Delta ECR = 7.1\%$.

Q.10: Please explain why the impact of fuel relocation on the severity of a LOCA could be greater for MOX fuel than for UO₂ fuel at the same burnup.

A.10: Experts have concluded that MOX fuel may experience more severe relocation effects than UO₂ fuel at the same burnup. The IPSN study above did not explicitly consider MOX fuel, but stated that “it must be pointed out that that results of corresponding calculations with ... high burnup MOX fuels would have been more severe with regard to acceptance limits.” Grandjean, Hache and Rongier at 7.

IRSN, the successor to IPSN, has reiterated these concerns, stating in a recent presentation that for MOX fuel, a “higher initial energy” and an “enhance [sic] of fuel relocation impact” results in greater increases in PCT and ECR associated with relocation. V Guillard, C. Grandjean, S. Bourdon and P. Chatelard, “Use of CATHARE2 Reactor Calculations to Anticipate Research Needs,” SEGFSM Topical Meeting on LOCA Issues, Argonne National Laboratory, slides at 8-9 (May 25-26, 2004) (NRC ACN # ML041600261). A copy of this paper is attached to my testimony as **Exhibit F**. In the abstract for this presentation, the authors state that “a lack of knowledge on theses [sic] parameters [important for relocation] for irradiated UO₂ and *particularly MOX fuel* [emphasis added] may lead to reduce [sic] safety margins.”

MOX fuel may experience more severe relocation effects than UO₂ fuel at the same burnup because several characteristics that are important for relocation may be less favorable for MOX fuel. These include pellet fragment size and fuel-clad interaction.

Q.11: Please explain the basis for your concern regarding the pellet fragment size of MOX fuel and its impact on fuel relocation in a LOCA.

A.11: The IPSN calculations cited above demonstrate the high sensitivity of fuel relocation-induced increases in PCT and ECR to the filling ratio. The filling ratio, in turn, is a function of the average particle size of the relocated fuel fragments, in that smaller particles will in general result in greater packing of the relocated area and hence higher filling ratios.

The fuel relocation phenomenon has been observed in LEU fuel for rod burnups exceeding around 48 GWD/t. See Grandjean, Hache and Rondier at 2 (2001). This suggests that vulnerability to fuel relocation is associated with the development of the high-burnup “rim” region known to emerge in LEU fuel for burnups exceeding about 40-45 GWD/t. IPSN states

that “fuel fragmentation is clearly associated to [sic] burnup, with finer fragments at higher BU.” See Grandjean, Hache and Rondier at 2 (2001).

For During manufacture of MOX fuel using the MIMAS process (which will be used for the Duke LTAs), plutonium agglomerates --- macroscopic clumps of plutonium-rich particles --- occur in the fuel. Because the fissile material is concentrated in these clumps, very high local burnups result, due to the fact that the fission is occurring in a heterogeneous fashion. The ratio of local burnup within the agglomerates is on the order of 4-6 times the rod-average burnup, depending on the irradiation time. For instance, the agglomerate burn-up reaches about 60 GWD/t when the rod average is only around 18 GWD/t, and reaches 100 GWD/t when the rod average is only 28.4 GWD/t. As a result, high-burnup rim-like regions emerge in the outer layers of the plutonium agglomerates for much lower rod-average burnups than 40-45 GWD/t, because the local burnups within the plutonium agglomerates increase much more rapidly than the rod-average burnups. Thus it is reasonable to expect that the onset of fuel relocation in MOX fuel may occur at lower rod-average burnups than in LEU fuel. This would imply that MOX fuel will be vulnerable earlier in its irradiation history (and consequently for a longer time) than LEU fuel. Also, the particle size distribution in MOX fuel will be smaller than in LEU fuel at the same rod-average burnup, to the extent that fine fragments are generated in the ultra-high burnup plutonium agglomerate regions.

Fuel fragmentation can also be caused by the stress induced by the stored-energy redistribution during the blowdown phase of a LOCA. A. Mailliat and M. Schwarz, “Need for Experimental Programmes on LOCA Issues Using High Burn-Up and MOX Fuels,” NUREG/CP-0176, Proceedings of the Nuclear Safety Research Conference at 436 (May 2002) (NRC ACN # ML021710793) (hereinafter “Mailliat and Schwarz”). A copy of this paper is attached to my testimony as **Exhibit G**. Because MOX fuel has a lower thermal conductivity and a higher radial temperature gradient than LEU fuel, it could experience greater fuel fragmentation during the blowdown and more severe relocation effects as a result.

According to two out of four NRC experts who participated in the 2001 PIRT panel on LOCAs and high-burnup fuel, the composition of fuel (i.e. a specified MOX composition) is of “high importance” for consideration of fuel relocation effects because it “may affect the amount of fine grain material after relocation. Fuel structure and mechanical properties are influenced by fuel type.” See NUREG/CR-6744, “Phenomenon Identification and Ranking Tables for Loss-of-Coolant Accidents in Pressurized and Boiling Water Reactors Containing High-Burnup Fuel,” Appendix D, Table D-1 at D-67 (December 2001) (NRC ACN # 013540623) (hereinafter “NUREG/CR-6477”). Relevant portions of this report are attached to my testimony as **Exhibit H**. One expert concluded that fuel composition was of moderate importance to relocation, stating that “the consequence of fuel fragments relocation (higher local decay heat and higher cladding temperature) could be more effective with MOX fuel than with UO₂ fuel” but that “the viscoelastic properties of the MOX should impair the fuel fragments relocation at high burnup.” *Id.* at D-67. A fourth expert concluded that fuel composition would be of only low importance to relocation. *Id.* at D-67. This difference of expert opinion highlights the inadequacies of the experimental database with regard to integral tests of MOX fuel under design-basis LOCA conditions, and underscores the significant uncertainties in Duke’s design-basis LOCA analysis.

Q.12: Please explain the basis for your concern regarding the effects of fuel-clad interaction within the MOX LTAs and their impact on fuel relocation in a LOCA.

A.12: I am concerned about differences between MOX and LEU fuel with respect to fuel-clad bonding and the impact of such differences on fuel relocation behavior during a design-basis LOCA. According to IPSN (now IRSN), tight fuel-clad bonding may delay the onset of fuel relocation. Mailliat and Schwarz at 433. Tight bonding has also been observed at the Halden reactor in Norway to retard the rate of balloon formation. Nuclear Energy Agency, NEA/CSNI/R(2003)9, *Ongoing and Planned Fuel Safety Research in NEA Member States* at 79 (March 5, 2003). Relevant excerpts of this report are attached to my testimony as **Exhibit I**. During NRC's recent expert elicitation (PIRT) process on LOCA issues for high-burnup fuel, all four participating experts agreed that "chemical and mechanical bonding between the fuel pellet and the cladding ..." was of high importance to the fuel relocation phenomenon, because "bonding could significantly affect the relocation characteristics by impeding pellet fragment movement." NUREG/CR-6744, Table D-1 at D-69. It has been confirmed that MOX fuel is more resistant to clad failures due to pellet-clad mechanical interaction (PCMI) than LEU fuel, even at high burnups. Nuclear Energy Agency, NEA/NSC/DOC(2004)8, *International Seminar on Pellet-Clad Interactions with Water Reactor Fuels*, at 20 (May 6, 2004). Relevant excerpts of this report are attached to my testimony as **Exhibit J**. This phenomenon is not well-understood but may imply that the pellet-clad bond is weaker for MOX fuel, in which case MOX fuel may have a greater propensity to earlier and more extensive fuel relocation than LEU.

In Duke's April 14, 2004, Response to BREDL's first set of discovery requests, Duke stated that the Framatome design-basis LOCA analysis for the MOX LTAs did not assume any fuel-clad bonding and was therefore "conservative" with respect to the requirement that the degree of cladding swelling not be underestimated. *Id.* at 14. However, in the absence of an assessment of whether and to what extent the pellet-clad interaction is weaker in MOX fuel than in LEU fuel, there is no way of knowing the degree to which this assumption is conservative for MOX fuel. Therefore, Duke's failure to properly account for this phenomenon contributes another uncertainty to the safety margin associated with Duke's design basis LOCA calculation.

Moreover, there is evidence to contradict Duke's assertion that "deterministic LOCA evaluations typically based on data taken from unirradiated cladding" are conservative with respect to clad swelling. According to IPSN (now IRSN), results from the PBF-LOC experiments found that irradiated rods experienced greater clad deformation than unirradiated rods during design-basis LOCA conditions. *See* Mailliat and Schwartz at 432. There is simply no way to determine whether Duke's design-basis LOCA analysis underestimates or overestimates the degree of clad swelling (and hence the degree of fuel relocation) for MOX LTAs without additional experimental data from integral LOCA tests of high-burnup MOX fuel rods. Given the lack of data, BREDL finds unpersuasive the NRC's 1999 speculation, quoted by Duke in its April 14, 2004 set of responses to BREDL's discovery requests, that "a major effect is not expected" with regard to differences in pellet-clad bonding between MOX and LEU. *Id.* at 15.

Q.13: Please explain the basis for your concern regarding clad balloon size and its impact on the severity of fuel relocation affecting the MOX LTAs in a LOCA.

A.13: The MOX LTAs will use M5 cladding, as compared to the Zircaloy-4 or ZIRLO cladding that is extensively used in US PWRs. According to IRSN, M5 will form larger balloons than Zircaloy-4 in a design-basis LOCA because it remains more ductile during irradiation. October 2003 IRSN presentation to NRC at 24. The greater retained ductility of M5 as a function of burnup compared to Zircaloy-4 can result in a greater M5 balloon size during a design-basis LOCA for fuel rods of the same burnup. Larger balloons increase the space available for fuel fragments to fall and hence result in a greater propensity for fuel relocation during a LOCA, with an associated increase in PCT and local clad oxidation.

Q.14: A group of experts from Electricité de France (EDF), Framatome ANP and the French CEA recently challenged IRSN's assertion that M5 cladding would form bigger balloons during a LOCA than zircaloy-4 in a presentation at Argonne National Laboratory. Please explain your view of this position.

A.14: I do not believe the EDF presentation responds adequately to the issue that IRSN has raised. Their claim is that the Edgar creep tests --- which indicated a greater ductility and a larger balloon size for M5 than for zircaloy-4 --- are not the appropriate tests to actually evaluate balloon size during LOCAs. Ramp tests utilizing pre-hydrated cladding samples, which EDF asserts are more representative of LOCA conditions, indicate that the balloon size for M5 is not actually greater than for zircaloy-4.

Obviously, a ramp test would be more similar to the conditions experienced during a LOCA than a steady-state creep test. However, neither creep tests nor ramp tests utilizing pre-hydrated but unirradiated cladding materials adequately simulate all the relevant phenomena that could affect balloon formation during a LOCA involving high-burnup fuel. For example, a well-known property of M5 cladding is that it generates a thinner oxidation layer during normal irradiation as a function of burnup than zircaloy-4. Zircaloy-4 at high burnups tends to generate a thick oxidation layer that's prone to spalling. Spalling will cause spatial inhomogeneities in the clad temperature that negatively affect ductility, leading to earlier cladding ruptures during a LOCA and hence smaller balloon sizes. I don't think that the ramp tests described by EDF take that effect into account. Therefore, I don't believe that the EDF presentation fully addresses the differences that would be observed in actual irradiated fuel with regard to the ductility and the balloon size of M5 compared to that of zircaloy-4.

This question remains unresolved because there is an absence of experimental data on the performance of high-burnup, M5-clad fuel, under design-basis LOCA conditions. The Electric Power Research Institute (EPRI) and Areva (parent company of Framatome ANP) apparently continue to deny NRC access to samples of irradiated high-burnup M5-clad LEU fuel for testing at Argonne National Laboratory. Letter from Ashok C. Thadani, NRC, to David Modeen, EPRI (April 21, 2004) (ADAMS ACN # ML041130490). A copy of this letter is attached to my testimony as **Exhibit K**. This lack of cooperation can only cause further delays in the ability of NRC to obtain the experimental data it needs to confirm the safety of high-burnup M5-clad fuel (whether LEU or MOX).

I would underscore the admission of M. Blanpain of AREVA during the ACRS Reactor Fuels Subcommittee Meeting on April 21, 2004 that MOX fuel irradiated in France is predominantly clad in Zircaloy-4, and only “some M5 fuel rods with MOX for experimental purposes” have been used in France. See Transcript at 61-62. For some reason, France is reluctant to use M5-clad MOX fuel domestically and is primarily producing it for export to Germany (and now to the United States). However, even in Germany the use of M5-clad MOX has been extremely limited. And I am unaware of any integral LOCA tests performed with irradiated M5-clad MOX fuel.

Q.15: Please explain the basis for your concern regarding the impact of fuel relocation on the ability of the MOX LTA core to satisfy the regulatory requirement for coolable core geometry.

A.15: As stated above, fuel relocation increases the local linear heat generation rate. The maximum flow blockage that will preserve a coolable geometry depends on the assumed heat source and the heat transfer properties of the fuel bundle. As IRSN points out, acceptable bundle blockage ratios were derived based upon arrays of unirradiated fuel rods, and did not take into account fuel relocation and its associated impacts on the redistribution of the decay heat source within the fuel rods. IRSN presentation to NRC at 29 (October 23, 2003). IRSN restated its concern in a recent presentation:

“The impact of fuel relocation in fuel rod balloons, as was observed in all in-reactor tests with irradiated fuel, leading to an increase in local power (lineic and surfacic) ..., on the coolability of the blocked region, is still fully questionable and should be addressed by specific analytical tests with a simulation of fuel relocation.”

C. Grandjean and G. Hache, “LOCA Issues Related to Ballooning, Fuel Relocation, Flow Blockage and Coolability,” SEGFSM Topical Meeting on LOCA Issues, Argonne National Laboratory at 23 (May 25-27, 2004) (emphasis in original). A copy of this paper is attached to my testimony as **Exhibit L**.

Thus, any analysis that does not take this into account is incomplete and is likely to be non-conservative. Lack of consideration of this phenomenon will be of greater concern for the MOX LTA core to the extent that the MOX LTAs have a smaller margin to regulatory limits than LEU fuel.

Q. 16: Please explain the basis for your concern regarding the smaller safety margins for MOX fuel with respect to peak clad temperature in a LOCA.

A.16: As Duke's calculations have demonstrated, the PCT in a design-basis LOCA is higher for a MOX rod than for an LEU rod in the same position in the core. Duke MOX LTA LAR at 3-43 (February 27, 2003). The margin to the 10 CFR §50.46 PCT limit of 2200°F is therefore smaller for a MOX rod than for an LEU rod in the same position.

At high burnups, the linear heat generation rate for MOX fuel is generally higher than that for LEU fuel. This, in turn, results in increased centerline temperature and stored energy, therefore reducing the margin to design-basis LOCA regulatory limits. BREDL maintains that every reduction in margin associated with MOX fuel use, coupled with the non-conservatism of ignoring fuel relocation effects, reduces confidence in Duke's design-basis LOCA analysis of the MOX LTA core.

Because there is little or no experimental data to conclusively validate the impact of relocation on either LEU or MOX fuel, a design-basis MOX LTA LOCA analysis that takes relocation into account would be highly uncertain --- with a resulting large uncertainty in the calculation of the relocation-associated increase in PCT of a MOX LTA fuel rod compared to the relocation-associated increase in PCT of an LEU fuel rod. For instance, if the MOX filling ratio is 70% and the LEU filling ratio is only 40%, because of a greater quantity of fine fragments in the MOX fuel, the increase in PCT could be nearly three hundred degrees Fahrenheit greater for MOX than for LEU (assuming that no other MOX-related effect, such as a greater initial linear heat generation rate, results in an even more severe increase in PCT associated with relocation).

The PCT calculated by Duke for the MOX LTA is 2018°F. Obviously, a relocation-associated increase in PCT of, say 313°F (associated with a 70% filling ratio for LEU fuel), would result in an exceedance of the 2200°F limit by 131°F. On the other hand, if the LEU filling fraction is closer to 40%, the increase in PCT would only be about 40°F, and the LEU fuel would still be in compliance with the regulatory limit. Thus the MOX LTAs could well be limiting with respect to LOCA compliance if relocation is fully accounted for.

These significant uncertainties should be reflected in Duke's analysis, and NRC approval should be contingent upon a demonstration that uncertainties of this magnitude do not undermine reasonable assurance of adequate protection of the public health and safety. I do not believe that such a finding can be made, given the potential severity of the relocation phenomenon and its associated uncertainties.

Q.17: Please discuss how, in your opinion, the gaps in the experimental database for the behavior of high-burnup, M5-clad MOX fuel during LOCAs can be reduced.

A.17: The only way to fully address the uncertainties associated with the behavior of high-burnup, M5-clad MOX fuel during LOCAs is to conduct integral LOCA tests of such fuel, fabricated with the same specifications as the lead test assemblies that are under consideration here, and irradiated to a range of burnups, including the maximum of 60 GWD/t that Duke has requested

in its LAR. The proposed Phébus test series would likely make a substantial contribution to reducing the level of uncertainty associated with MOX fuel behavior during LOCAs.

These integral tests could be supplemented with separate-effects tests specifically designed to look at fuel relocation as a function of burnup for both MOX and LEU fuel, and to measure the relative susceptibility to relocation of the two types of fuels. The Halden IFA-650 test, which I understand is being designed to examine fuel relocation effects in LEU fuel, could help to resolve some of these questions. But similar tests on mixed oxide fuel will also be needed. And separate effects tests cannot reproduce the complex, interrelated set of thermal-hydraulic and mechanical phenomena that would occur during a LOCA and would affect fuel relocation.

Q.18: Does the Staff's Safety Evaluation Report (SER) provides any insight into the issues raised by Contention I?

A.18: The SER doesn't address the issues that we've raised concerning the impact of relocation. So to that extent, it doesn't affect my conclusions at all. Members of the Staff admitted during the ACRS subcommittee meeting on the LTA LAR application that they have not done their own independent calculations to confirm Duke's LOCA analyses. The Staff has only checked Duke's results for internal consistency, rather than doing any of its own simulations. Therefore, to the extent that the Staff claims to have independently verified the adequacy of Duke's LOCA analysis, I do not believe that claim is correct.

Q.19: Does this conclude your testimony?

A.19. Yes.