FRAMATOME ANP

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FRAMATOME ANP, Inc.

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Document Control Desk
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Final Response to RAI on BAW-10238(P), Revision 1, "MOX Fuel Design Report."

Ref.: 1. Letter, Drew G. Holland (NRC) to James F. Mallay (Framatome ANP), "Request for Additional Information (RAI) – Topical BAW-10238(P), Revison 1, 'MOX Fuel Design Report'," (TAC NO. MB7550), October 8, 2003.

Ref.: 2. Letter, James F. Mallay (Framatome ANP), to Document Control Desk (NRC), "Partial Response to RAI on BAW-10238(P), Revision 1, 'MOX Fuel Design Report'," NRC:03:072, October 27, 2003.

Ref.: 3. Letter, James F. Mallay (Framatome ANP), to Document Control Desk (NRC), "Partial Response to RAI on BAW-10238(P), Revision 1, 'MOX Fuel Design Report'," NRC:03:080, November 24, 2003.

Ref.: 4. Letter, James F. Mallay (Framatome ANP), to Document Control Desk (NRC), "Partial Response to RAI on BAW-10238(P), Revision 1, 'MOX Fuel Design Report'," NRC:03:082, December 5, 2003.

Ref.: 5 Letter, James F. Mallay (Framatome ANP), to Document Control Desk (NRC), "Partial Response to RAI on BAW-10238(P), Revision 1, 'MOX Fuel Design Report'," NRC:03:086, December 16, 2003.

The NRC issued a request for additional information (RAI) on the MOX fuel design topical report (Reference 1). References 2 through 5 contained responses to all but two of the questions in the RAI.

Attached please find responses to the two remaining questions (14 and 27). Also included in the attachment are responses to the last two supplementary questions posed by the NRC during its audit of the topical report on November 18 through 20, 2003. These responses are provided in two attachments – one proprietary and one non-proprietary.

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Framatome ANP considers some of the information contained in Attachment 1 to be proprietary. The affidavit provided with the original submittal of the topical report satisfies the requirements of 10 CFR 2.790(b) to support the withholding of this information from public disclosure.

Very truly yours,

James F. Mallay, Director
Regulatory Affairs

Enclosure

cc: D. G. Holland
R. E. Martin
E. S. Peyton
Project 728

Responses to RAI on Topical Report
BAW-10238(P), MOX Fuel Design Report

In all responses, "BAW-10238" means *MOX Fuel Design Report*, BAW-10238(P), Revision 1, May 2003.

Question 14: *In section 6.1.7, it states that the Mark-BW/MOX1 axial gap between the top nozzle and reactor internals was analyzed to show that sufficient margin exists to accommodate the fuel assembly growth for the design burnup (Reference 1). However, Reference 1 was analyzed for uranium fuels. Please explain this discrepancy. Also, since this section refers to Reference 1 please explain why the shoulder gap is analyzed differently from what was used in Reference 1 and provide a reference for where the direct modeling of the shoulder gap using the described method is approved for use.*

Response 14: The fuel assembly growth model used for the Mark-BW/MOX1 fuel is the same as that used for the LEU fuel. Fuel rod growth and fuel assembly design features influence fuel assembly guide thimble growth. As shown in Figure 2 of Reference Q14.1, MOX fuel rod growth data obtained in Europe is well within the rod growth ranges for LEU fuel, which confirms the use of the LEU fuel assembly growth model for this application. In addition, the fuel assembly structure is identical between the LEU and MOX fuel designs, leading to the same states of stress in the structure which affect guide thimble growth. The structural materials, load paths, and the internal and external loadings are the same. Examples of the internal loadings are the component weights and the spacer grid-fuel rod slip forces. Examples of the external loadings are the holddown spring compressive forces and the hydraulic loadings due to component pressure drop.

The direct modeling of shoulder gap for M5® fuel designs is approved per the M5® topical report (Reference Q14.2). A conservative shoulder gap closure model was used for the MOX design, resulting in a minimum shoulder gap of [ ] inch for a maximum rod burnup of 60,000 MWd/MThm, which is the maximum lead assembly burnup. The maximum batch rod burnup is 50,000 MWd/MThm.

Fuel rod growth and fuel assembly growth can be modeled independently. Using that approach, shoulder gap closure is calculated as the fuel rod growth minus the fuel assembly growth. Alternatively, the shoulder gap closure can be modeled directly. Either approach can be used, regardless of fuel pellet material. Therefore, direct modeling of the shoulder gap is applicable to MOX.

Q14.1 P. Blanpain et al., "Recent Results from the In Reactor MOX Fuel Performance in France and Improvement Programme," *ANS Fuel Performance Meeting*, March 2-6, 1997, Portland, Oregon.

Q14.2 BAW-10227P-A, *Evaluation of Advanced Cladding and Structural Materials (M5) in PWR Reactor Fuel*, February 2000.

Question 27: *In section 8.5.2, it states that the extended PIE may occur after reactor restart. Please specify exactly which tests will be performed in the extended PIE, describe the test methods planned and the acceptance criteria for each test.*

Response 27: The basic PIE consists of the first five items in Table 8.1 of BAW-10238, and the extended PIE consists of all items. The extended PIE tests will be performed as listed in Table 8.1 after the second and third cycles of irradiation of the lead assemblies. However, the extent of the inspections may be limited by the availability of fuel assemblies. For example, if only one lead assembly is irradiated for a third cycle, only one will be examined after the third cycle, even if Table 8.1 specifies that two assemblies will be examined.

The following paragraphs describe the test methods and discuss the expected values for each measurement. The measurement data are used to create empirical models for prediction of fuel behavior relative to the design criteria. Current test methods are described, but improved or innovative methods may be used if they become available.

Grid width: Two adjacent faces of the intermediate spacer grids nearest the top of the assembly are measured. Grid measurements are taken with an LVDT, then averaged. The fractional grid growth is determined from the as-irradiated and initial widths and expressed as a percentage. The acceptance criterion is that the fractional grid growth *G*, expressed as a percentage, may not exceed the upper tolerance limit as a function of burnup. The upper tolerance limit is updated periodically based on reactor experience measurements. The current upper tolerance limit based on the latest available data is

[ ] (Q27.1)

where *b* is the maximum rod average burnup expressed in GWd/MThm. Equation Q27.1 is applicable for burnups of [ ] GWd/MThm. If the fractional grid growth exceeds the upper tolerance limit, an evaluation will be performed to determine the cause and determine whether any corrective action is necessary.

Fuel rod oxide thickness: The cladding oxide thickness is measured by determining the distance from the surface of the rod to the conductive metal. An eddy current contact probe is used to determine that distance, which is made up of the oxide layer and the crud film. The inspections are performed on the second span (from the top), which experiences the highest operating temperatures and hence the greatest oxide thickness. The test methods differ for peripheral and interior rods. For peripheral rods, the probe is passed along the length of the rod. Because of the mid-span mixing grid, the scan is divided into two sections. To reduce noise, the measured data are smoothed using a moving average. The maximum value of the moving average for a given rod is expected to be less than 50 μm. For interior rods, the eddy current probe is moved perpendicular to the axis of the fuel rods. The offset from the metal surface reaches a minimum when the probe contacts a fuel rod. The minimum offsets are recorded for both insertion and removal of the probe, and the two values are averaged for each fuel rod. The average is expected to be less than 50 μm. This expected range is not performance-based, but represents a conservative margin of safety relative to the performance-based criterion (100 μm) documented in Reference Q27.1. If the results of the PIE indicate that the expected value is exceeded, an evaluation will be performed to determine the cause and determine whether any corrective action is necessary.

Grid oxide thickness: Grid oxide thickness, like fuel rod oxide thickness, is measured with an eddy current probe. Measurements are taken on the intermediate spacer grids nearest the top of the assembly. Several measurements are taken on each of two adjacent faces, and the measurements on each face are averaged. The maximum expected value of the average oxide thickness for any face is less than [68] μm. As above, for the fuel rod cladding oxide thickness criterion, if the results of the PIE indicate that the expected range is exceeded, an evaluation will be performed to determine the cause and determine whether any corrective action is necessary.

Fuel assembly RCCA drag force: An RCCA is inserted into the irradiated fuel assembly. The RCCA is connected to a handling tool, and the tool is connected to a power hoist through a load cell. As the RCCA is withdrawn and reinserted, the load and the RCCA position are recorded. The expected maximum drag force is less than [ ] lbf while the tip of the RCCA is in the guide thimble dashpot or [ ] lbf while the tip of the RCCA is above the guide thimble dashpot. If these values are exceeded, an evaluation will be performed to determine the cause and determine whether any corrective action is necessary.

Guide thimble plug gauge: Cylindrical gauges of various lengths and diameters are lowered sequentially into a guide thimble. If a gauge passes to the bottom of the guide thimble, that fact is noted. If it stops at some other elevation, the elevation is noted. There is no acceptance criterion. That is appropriate because plug gauging is used only to characterize the position and amount of curvature in the guide thimbles, not to determine whether RCCA insertion times will be acceptable.

Water channels (fuel rod bowing): Water channel spacing is the distance between adjacent rods in an assembly at the midplane between spacer grids. These spacings can be classified as (1) fuel rod to fuel rod or (2) fuel rod to guide thimble. Since the guide thimbles and instrument tube have the same diameter, the instrument tube is treated as a guide thimble. Water channel measurements are taken between all fuel rods, guide thimbles, and instrument tubes. The measuring device uses a probe that is a thin wand with strain gages attached to leaf springs. The probe measures the distance between pairs of rods. For measurements in one of the orthogonal directions, $16 \times 17 = 272$ gaps are measured. There are 222 fuel rod to fuel rod gaps and 50 fuel rod to guide thimble gaps. For each of the two classes of gaps, the standard deviation is computed. The process is repeated for each of the seven spans and both of the orthogonal directions. The acceptance criterion is that the maximum standard deviation may not exceed a burnup-dependent value as reported in Reference Q27.2. [

] Larger values of the maximum standard deviation will require an evaluation to determine whether a local peaking penalty must be applied.

Q27.1 BAW-10227P-A, *Evaluation of Advanced Cladding and Structural Materials (M5) in PWR Reactor Fuel*, February 2000.

Q27.2 BAW-10186P-A Revision 1, *Extended Burnup Evaluation*, April 2000.

Supplemental Question 3: *Section 6.1.6 discusses the use of European rod bow data to support the Mark-BW/MOX1 design. Please explain how the European database can be used with the approved U.S. methods to show the applicability of the LEU rod bow experience to MOX fuel.*

Response to Supplemental Question 3: During operation, friction forces are generated between fuel rods and the fuel assembly cage due to differential thermal expansion and irradiation induced growth. These loads can cause creep bow of the fuel rods, which alters the design pitch dimensions between adjacent rods. The major effects of fuel rod bowing are (1) the reduction in fuel rod to fuel rod spacing and resulting decrease in margin to departure from nucleate boiling ratio (DNBR) and (2) the increase in fuel rod to fuel rod spacing and resulting increase in local power peaking.

Rather than placing design limits on the amount of bowing that is permitted, the effects of rod bowing are included in the cladding overheating analysis by limiting fuel rod powers when bowing exceeds a predetermined amount. Framatome ANP has established a rod-to-rod clearance limit below which a penalty is imposed by a reduction in the DNBR and above which no reduction in DNBR is necessary.

The Framatome ANP method of establishing fuel rod bow and including these effects is described in Reference SQ3.1. The method was reiterated in Reference SQ3.2.

EUROPEAN FUEL ROD BOW DATA

Presently no U.S. MOX fuel rod data exist, so European MOX fuel data must be used for comparison with LEU fuel data. The European rod bow database includes data representing LEU and MOX fuel with Zircaloy-4 cladding and LEU fuel with M5® cladding. There is no available data for MOX fuel with M5® cladding.

Figure SQ3.1 presents the available European data concerning the influence of cladding and pellets on rod bow. It presents the water channel gap closure (%) per assembly based on post-irradiation measurements for AFA LEU and MOX fuel with Zircaloy-4 cladding and for LEU fuel with M5® cladding.

AFA LEU and MOX fuel with Zircaloy-4 Cladding

For the European application, rod bow evolution due to irradiation is taken into account in the design studies by means of a water channel closure model versus fuel assembly burnup.

This law has the following shape:

[ ] (SQ3.1)

Here *CR* is the gap closure (%), *a* and *b* are constants, and BU is the assembly average burnup. The same law is used for MOX and LEU assemblies for the European application.

The validity of this law for MOX assemblies has been checked on the following assemblies, all of the AFA type:

- 3 assemblies, after 1, 2, and 3 cycles, at Saint Laurent B1 with assembly burnup of [ ] GWd/MThm at end of cycle 3,

- 2 assemblies after four cycles in Gravelines 4 with assembly burnup of [ ] GWd/MThm,
- 1 assembly after 5 cycles in Dampierre 1 with assembly burnup of [ ] GWd/MThm.

The rod to rod distances of peripheral rods are measured, at each mid-span, by an optical method inducing no load on the rods. For each span, the average and standard deviation of the water channel gaps are computed. Based on a 95/95 statistical method, the gap closure (%) is computed for each span with the highest value compared with the design law for gap closure.

Figure SQ3.1 shows the water channel gap closure measured on the MOX and LEU assemblies for the same fuel assembly design (AFA) and the same fuel rod cladding (Zircaloy-4). This comparison isolates the effects of the MOX pellets on fuel rod bow. Results show that the MOX fuel rod bow is well within that of the LEU fuel rod bow and actually trends to the lower side of the data. The design law is shown to be conservative for MOX assemblies. Note that the design law is specific to Framatome ANP, SSA (France).

LEU Fuel with M5® Cladding

Figure SQ3.1 also provides European rod bow data for LEU fuel with M5® cladding for comparison with similar fuel with Zircaloy-4 cladding for fuel assembly burnups up to [ ] MWd/MTU. The data is taken from Pentix fuel in Nogent 2 (1300 MWe), which uses an AFA 3G Zircaloy-4 structure and M5® cladding. Measurements were performed on 4 assemblies during three cycles. Additional rod bow data for Prelude LEU fuel with M5® cladding is provided from two experimental fuel assemblies, which were irradiated in Paluel 1 (1300 MWe) and measured during four cycles. This data shows that the M5® fuel rod bow is comparable to that of the Zircaloy-4 fuel rods for LEU fuel and is within the water channel gap closure design law.

Therefore, based on the European data, no significant difference appears between the LEU fuel rods with Zircaloy-4 and M5® cladding nor between the LEU and MOX fuel rods with Zircaloy-4 cladding.

U.S. FUEL ROD BOW DATA

Figure SQ3.2 provides U.S. fuel rod bow data, which includes data for LEU fuel with Zircaloy-4 and M5® fuel rod cladding. The data includes the Mark-B (15×15) and Mark-BW (17×17) fuel designs, in addition to the Alliance (17×17) and Advanced Mark-BW (17×17) lead assemblies. The lead assemblies comprise the M5® fuel rod cladding data. Figure SQ3.2 shows the maximum water channel gap standard deviation as a function of fuel assembly burnup and the corresponding limits as prescribed in Reference SQ3.2. The rod-to-rod distances through the fuel bundle are measured, at each mid-span, by a transducer inducing negligible load on the rods. For each span, the average and standard deviation of the water channel gaps are computed. The data reflects the maximum standard deviation in a given measured fuel assembly and is compared to the limits prescribed in Reference SQ3.2.

Figure SQ3.2 shows that the fuel rod bow is below the required limits for the Zircaloy-4 and M5® fuel rods for fuel assembly burnups of [ ] MWd/MTU and [ ] MWd/MTU, respectively. No significant difference is observed between the Zircaloy-4 and M5® fuel rods nor between the fuel design arrays, i.e., 15×15 and 17×17, which is consistent with the European database. The rod bow is shown to stabilize at higher burnup, while the fuel at higher burnup is not limiting from a thermal margin standpoint due to lower power.

APPLICABILITY OF EUROPEAN FUEL ROD BOW DATA

The rod bow trends established within the European database for LEU and MOX fuel and for Zircaloy-4 and M5® fuel rod cladding are considered applicable to the U.S. database. Note that the European fuel rod cladding bow trends are supported by similar results observed in the U.S data, i.e., no significant differences are observed for the Zircaloy-4 and M5® fuel rod bow, and the maximum bow remains within the required limits. As demonstrated in the European data, the MOX fuel rod bow is enveloped by the LEU fuel rod bow and the same design law is used for both the MOX and LEU fuel designs in Europe. The use of MOX fuel pellets does not degrade fuel rod bow performance for a given fuel rod and fuel assembly design. This is expected since friction forces between the fuel rod and fuel assembly cage are considered a main contributor to rod bow. The U.S. LEU fuel rod bow database, shown in Figure SQ3.2, shows similar rod bow performance for the range of fuel rod and fuel assembly designs within the U.S. fuel product. This range of designs includes the Advanced Mark-BW, which is the Mark-BW/MOX1 with LEU fuel rods. Thus, the U.S. LEU fuel rod bow database is applicable for the implementation of MOX pellets, and the limits established in Reference SQ3.2 will be used for the U.S. MOX fuel design.

On the basis of comparative evaluation of empirical data, the fuel rod bow for the Advanced Mark-BW/MOX1 fuel will be enveloped by the existing U.S. LEU data base. Thus, the fuel rod bow evaluation method presented in Reference SQ3.2 is considered applicable for the Mark-BW/MOX1 fuel.

Figure SQ3.1. European Water Channel Gap Closure Data for LEU and MOX Fuel

Figure SQ3.2. U.S. Rod Bow Data for Mark-B and Mark-BW Fuel Designs

SQ3.1 BAW-10147P-A Revision 1, *Fuel Rod Bowing in Babcock & Wilcox Fuel Designs*, May 1983.

SQ3.2 BAW-10186P-A Revision 1, *Extended Burnup Evaluation*, April 2000.

Supplemental Question 4: *Please list the approved methods that are to be used to analyze MOX fuel and explain why they are applicable to MOX.*

Response to Supplemental Question 4: The following methods are applicable to MOX:

ASME Code (Reference SQ4.1): The ASME Code has been accepted by the NRC for mechanical analysis of nuclear power plant components, and it is used in BAW-10238 for fuel cladding and fuel assembly structural components. The structural integrity of such components depends on the type of material, stress, temperature, and neutron fluence but not on the fuel pellet material. Methods of analysis in the Code are therefore applicable to MOX fuel as well as LEU fuel. Structural analysis results are reported in Section 6.1.1.1 of BAW-10238. Results of fatigue analysis are reported in Section 6.1.3 of BAW-10238.

BAW-10227P-A (Reference SQ4.2): This report has been approved by the NRC for use with LEU fuel. The following methods and criteria have been used for MOX and are applicable for the reasons stated below:

Cladding stress: In cladding stress calculations, the stress was compared with the unirradiated yield strength, which is independent of the fuel pellet material. The stress equations do not depend on the fuel pellet material. Therefore, this method is applicable to MOX fuel as well as LEU fuel. Results from these methods are reported in Section 6.1.1.2 of BAW-10238.

Cladding buckling: Calculations on cladding buckling used unirradiated properties, which are independent of the fuel pellet material. The buckling equations do not depend on fuel pellet material. Therefore, this method is applicable to MOX fuel as well as LEU fuel. Results from this method are reported in Section 6.1.1.2 of BAW-10238.

Cladding fatigue: The design method requires that the cladding fatigue usage factor be less than 0.9. This criterion is independent of the fuel pellet material, so it is applicable to MOX fuel as well as LEU fuel. The Condition I, II, and III events are likewise independent of the fuel pellet material. The methods for analyzing cladding fatigue correctly reflect the properties of MOX fuel. Therefore, the methods are applicable to MOX fuel as well as LEU fuel. Results from applying the criterion and methods are reported in Section 6.1.3 of BAW-10238.

Axial growth: The response to question 14 discusses the model for fuel assembly axial growth and justifies its applicability to MOX fuel. It also shows that the method of directly modeling the fuel rod shoulder gap, rather than determining gap closure from fuel rod growth and fuel assembly growth, is applicable to MOX fuel. Results from this model and method are reported in Section 6.1.7 of BAW-10238.

BAW-10231P Chapter 13 (Reference SQ4.3): This revision is under review by the NRC. It provides a new chapter (Chapter 13) that specifically addresses the performance of MOX fuel rods. All methods described in Chapter 13 may be used to analyze design changes for MOX once the report is approved. Results from methods described in Reference SQ4.3 are reported in Sections 6.1.2 (cladding strain), 6.1.3 (cladding fatigue), 6.1.5 (oxidation and hydriding), 6.1.8 (fuel rod internal pressure), 6.2.2 (creep collapse), 6.2.4 (overheating of fuel pellets), and 6.2.5 (pellet-cladding interaction) of BAW-10238. As is mentioned in Section 6.2.5 of BAW-10238, pellet-cladding interaction is addressed by considering cladding strain and fuel melting. Note that citations of BAW-10231P in BAW-10238 should in fact be citations of Reference SQ4.3 and Reference SQ4.4.

BAW-10156-A (Reference SQ4.5): This topical report describes the LYNXT thermal-hydraulic code that has been approved by the NRC for use with LEU fuel. Note that this report is not cited in BAW-10238, however it is used for supporting analyses where core hydraulic calculations are necessary. The following design analyses have been performed for MOX fuel using the capabilities described in this report which are applicable for the reasons stated below:

Fretting: The technique for calculating hydraulic forces associated with fuel rod fretting concerns relies on the calculation of flow distributions within the core. These capabilities are described in this report and are applicable to MOX fuel as well because the calculation of flow distributions within the core is not dependent on the fuel pellet material. Therefore, the techniques for calculating hydraulic forces may be used to analyze design changes for MOX. Results from applying this capability are reported in Section 6.1.4 of BAW-10238.

Fuel assembly liftoff: The technique for calculating hydraulic lift forces relies on the calculation of flow distributions within the core. These capabilities are described in this report and are applicable to MOX fuel as well because the calculation of flow distributions within the core is not dependent on the fuel pellet material. Therefore, the techniques for calculating hydraulic lift forces may be used to analyze design changes for MOX. Results from applying this capability are reported in Section 6.1.9 of BAW-10238.

BAW-10186P-A (Reference SQ4.6): This report has been approved by the NRC for use with LEU fuel. It presents a method for analyzing fuel rod bow and acceptable limits on the amount of bow. Reference SQ4.6 lists three areas where fuel rod bow can affect assembly performance: (1) thermal-hydraulic design, (2) local power changes, and (3) fuel cladding mechanical design.

Thermal-hydraulic design: Apart from changes in local power, thermal-hydraulic design is concerned only with heat transfer from the cladding to the coolant and flow of the coolant; it is independent of the fuel pellet material.

Local power changes: The effects of rod bow on local power may be different for MOX than for LEU fuel. Differences in fuel behavior between LEU and MOX are reflected in the peaking uncertainty. The peaking penalty used for MOX core designs reflects the amount of rod bow expected from LEU fuel designs and the neutronic properties of MOX fuel. As is discussed in the response to supplemental question 3, MOX fuel rods are not expected to bow more than LEU fuel rods. The lead assembly PIE exams will confirm the bow behavior of MOX.

Fuel cladding mechanical design: Reference SQ4.6 considered the possibility that two fuel rods would contact each other and cause fretting, but it concluded that fretting was not a concern because of the small relative motion and low contact force. Relative motion depends on coolant flow rather than the fuel pellet material, and contact force depends on the design and mechanical properties of the cladding rather than the fuel pellet material. MOX fuel rods are not expected to bow more than LEU fuel rods. Therefore, fretting of fuel rods against fuel rods is not a concern for MOX fuel.

Therefore, with correct treatment of the effects of MOX neutronics on the peaking penalty, the method for analyzing fuel rod bow and acceptable limits on the amount of bow from Reference SQ4.6 are applicable to MOX. Results from applying the method are reported in Section 6.1.6 of BAW-10238.

The analysis of internal fuel rod hydriding in BAW-10238, Section 6.2.1, is specific to MOX, so other approved methods are not needed. Future design changes will not increase the total amount of hydrogen beyond the limits described in BAW-10238 unless it can be shown that such changes will not degrade fuel performance.

BAW-10084P-A (Reference SQ4.7): This report has been approved by the NRC for use with LEU fuel. The methods in this report are applicable to MOX fuel as well, with inputs from the COPERNIC computer code discussed above. Differences in fuel behavior between LEU and MOX are reflected in the inputs to the program, which include time-dependent fuel rod internal pressures, cladding temperatures (at the inside and outside surfaces), and neutron fluxes. Apart from these inputs, the creep performance of the cladding is not dependent on fuel pellet material. Therefore, the methods for calculating creep collapse described in this report may be used to analyze design changes for MOX. Results from applying this method are reported in Section 6.2.2 of BAW-10238.

BAW-10199P-A (Reference SQ4.8): This report has been approved by the NRC for use with LEU fuel. It is applicable to MOX fuel as well because it describes the limits on the heat transfer to the coolant and is not dependent on the fuel pellet material. Therefore, the correlations described in this report may be used to analyze design changes for MOX. Results from applying this method are reported in Section 6.2.3 of BAW-10238.

DPC-NE-1003 (Reference SQ4.9): This report is under review by the NRC. It specifically addresses the neutronic performance of MOX fuel. All methods described in this report may be used to analyze design changes for MOX once the report is approved.

DPC-NE-2005P-A (Reference SQ4.10): This report has been approved by the NRC for use with both MOX and LEU fuel. All methods described in this report may be used to analyze design changes for MOX.

BAW-10133P-A (Reference SQ4.11) and BAW-10133P-A Revision 1 Addendum 1 (Reference SQ4.12): These reports have been approved by the NRC for use with LEU fuel. The methods use an elastic model for the cladding. The methods are not dependent on the fuel pellet material. Therefore, the methods for calculating seismic responses described in these reports are applicable to MOX fuel as well as LEU fuel. Note that References SQ4.11 and SQ4.12 are not cited in BAW-10238, but they are used for supporting analysis. Results from applying these methods are reported in Section 6.3.4 of BAW-10238.

SQ4.1 American Society of Mechanical Engineers, *Boiler and Pressure Vessel Code*, Section III, Nuclear Power Plant Components, 1992 Edition.

SQ4.2 BAW-10227P-A, *Evaluation of Advanced Cladding and Structural Materials (M5) in PWR Reactor Fuel*, February 2000.

SQ4.3 BAW-10231P Chapter 13, *COPERNIC Fuel Rod Design Computer Code: Chapter 13 – MOX Applications*, July 2000.

SQ4.4 BAW-10231P-A, *COPERNIC Fuel Rod Design Computer Code*, June 2002.

SQ4.5 BAW-10156-A Revision 1, *LYNXT: Core Transient Thermal-Hydraulic Program*, August 1993.

SQ4.6 BAW-10186P-A Revision 1, *Extended Burnup Evaluation*, April 2000.

SQ4.7 BAW-10084P-A Revision 3, *Program to Determine In-Reactor Performance of BWFC Fuel Cladding Creep Collapse*, July 1995.

SQ4.8 BAW-10199P-A, *The BWU Critical Heat Flux Correlations*, August 1996.

SQ4.9 DPC-NE-1003 Revision 0, *Duke Power Company Nuclear Design Methodology Using CASMO-4/SIMULATE-3 MOX*, August 2001.

SQ4.10 DPC-NE-2005P-A Revision 3, *Duke Power Company Thermal-Hydraulic Statistical Core Design Methodology*, September 2002.

SQ4.11 BAW-10133P-A, *Mark-C Fuel Assembly LOCA-Seismic Analysis*, June 1986.

SQ4.12 BAW-10133P-A Revision 1 Addendum 1, *Mark-C Fuel Assembly LOCA-Seismic Analysis*, October 2000.