February 11, 2000

MEMORANDUM TO: Chairman Meserve
Commissioner Dicus
Commissioner Diaz
Commissioner McGaffigan
Commissioner Merrifield

FROM: William D. Travers **/RA/ by Frank J. Miraglia Acting For/**
Executive Director for Operations

SUBJECT: AGENCY PLAN FOR CONFIRMATORY RESEARCH ASSOCIATED WITH THE USE OF MIXED-OXIDE FUEL IN COMMERCIAL LIGHT WATER REACTORS

PURPOSE:

The staff informed the Commission in a memorandum (the reference memorandum) on “Mixed Oxide Fuel Use in Commercial Light Water Reactors” dated April 14, 1999, that it would advise the Commissioners of significant developments related to addressing mixed oxide (MOX) fuel issues. The purpose of this memorandum is to discuss the associated confirmatory research activities and provide a copy of the “Program Plan to Resolve Specific Technical Issues for MOX Fuel” (copy attached).

BACKGROUND:

It is expected that licensing activities associated with the use of MOX in commercial power plants will begin to become active in mid-2000. Experience in Europe suggests that the technical and regulatory issues identified in the reference memorandum can be satisfactorily resolved. Based on that experience, the staff has not identified any risk-significant issue associated with the use of MOX fuels in U.S. commercial nuclear power plants. However, some of the technical issues will be unique because of the difference between weapons-grade MOX fuel and reactor-grade MOX fuel. Therefore, the staff will be developing certain capabilities in order to effectively review MOX core license applications and to confirm the above conclusion.

In March 1999, the Department of Energy (DOE) signed a contract with Duke Power, Cogema, Stone & Webster, and Limited Liability Corporation (MOX Consortium) to provide fabrication, radiation services, and utilization of MOX fuels in commercial nuclear power plants.

In the referenced memorandum, the staff discussed the technical issues related to the utilization of weapons-grade MOX fuel in commercial light water reactors.

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Since then, the staff met with representatives of DOE and the MOX Consortium to discuss the schedule for licensing of the MOX fabrication facility, the technical approach to MOX fuel use, and the preliminary planning estimates for licensing activities. Based on the preliminary planning, MOX fuel review efforts could begin in mid-2000 for topical reports to revise vendor analysis tools, with an application for a license amendment expected by August 2001 for loading two MOX fuel lead test assemblies in McGuire Unit 2. Applications for license amendments for the MOX fuel batch utilization are scheduled to be submitted to the staff in early 2004 for an estimated MOX fuel loading in September 2007 at the North Anna 1 nuclear power plant and October 2007 for the Catawba plant.

The Office of Nuclear Regulatory Research (RES) is responsible for developing the necessary data and tools to support the Office of Nuclear Reactor Regulation review of MOX fuels to ensure that the requirements in 10 CFR 50.46, Appendix A to 10 CFR Part 50, and Appendix K to 10 CFR Part 50 are met.

In the reference memorandum, the staff identified a number of technical issues that need to be addressed in the review of MOX fuel. The attachment to this paper describes the RES efforts needed to support this review. The remaining issues will be addressed in accordance with the guidelines of the Standard Review Plan as part of the review of the MOX fuel application.

DISCUSSION:

The Program Plan presented in the attachment assumes that the MOX Consortium will provide the data needed to obtain NRC approval for the utilization of MOX in commercial nuclear power plants, and it identifies research that will be performed to provide the necessary tools for NRR to confirm the acceptability of the MOX Consortium's submittals in a timely fashion. As stated earlier, the Europeans have extensive experience with the technical and regulatory issues associated with MOX fuels. The staff expects that the MOX Consortium will obtain, and make available to the NRC as part of its license application, the relevant data from the European experience that is needed to address those issues identified in the reference memorandum.

As discussed in the referenced memorandum, weapons-grade MOX fuel has a different mix of plutonium isotopes than reactor-grade MOX fuel, which affects the neutronics properties of the fuel. In addition, any MOX fuel has physical properties that are somewhat different from UO_2 fuel and this affects the thermal and mechanical performance of the fuel rods. These differences affect fabrication, transportation, storage, and the use of MOX fuel. The staff has grouped the technical issues associated with weapons-grade MOX into four areas: (a) reactor physics, (b) fuel behavior, (c) source terms, and (d) fuel fabrication, storage, and disposal. The RES efforts are targeted to address the technical issues for the first three areas. Although there may be a lack of cross-section data and publically available peer-reviewed critical experiments using MOX of the same form and composition as that containing weapons-grade plutonium, the staff has not identified specific technical issues related to the MOX fabrication, storage, and disposal. Should specific issues be identified regarding fuel fabrication, storage or disposal that require RES assistance, a workscope will be prepared by RES and NMSS to address those issues.

RES is planning to expand the ongoing high burnup expert-elicitation process as needed to address specific new issues that might arise related to MOX fuel. However, based on our current understanding of the technical issues, a preliminary schedule for the research program has been developed (attachment) and is summarized here.

(a) Reactor Physics

Because of the difference between MOX and UO_2 fuel, the NRC neutronics code will be modified to include MOX-specific models. Some of the models to be added to the neutronics code include multiple energy groups with upscatter, a modeling capability to capture the steep gradients between the two types of fuel assemblies, improved delayed-neutron precursor calculations, a revised decay heat model, and a method to handle local power peaking. The capability to calculate MOX cross-sections for input to the neutronics code will be needed. Therefore, the staff will obtain a lattice physics code for cross-section generation.

After the neutronics code is modified, it will be validated against relevant data. For reactor-grade MOX, the NRC will obtain data from the Halden reactor in Norway and the Organization for Economic Cooperation and Development (OECD). Startup and operational data from representative European power reactors that use MOX fuel will be useful for code validation. As part of the licensing reviews, the staff expects that the MOX Consortium will provide these data in support of its licensing case, and the data will then be available to the NRC for code validation. RES will work with NRR and the MOX Consortium to obtain the data from the lead test assembly program which the staff needs for the validation of the NRC neutronics code for weapons-grade MOX.

(b) Fuel Behavior

Although MOX and UO_2 fuels behave in a similar fashion during normal steady-state operation, subtle differences caused by different physical properties have some effects on fuel and cladding performance under accident conditions. Therefore, the staff must confirm that adequate bases exist to assure the integrity of the cladding, which represents the first barrier to the release of radioactive material to the atmosphere. Therefore, NRC fuel behavior codes (FRAPCON, FRAPTRAN) will be modified to account for altered material properties such as thermal conductivity, thermal expansion, and creep rates in order to analyze weapons-grade MOX fuel behavior under normal and transient conditions (e.g., LOCA, reactivity-initiated accidents).

To validate these fuel codes, the NRC plans to obtain data on reactor-grade MOX from the Halden reactor and from OECD. The staff expects that as part of the licensing reviews, information on the difference between reactor-grade and weapons-grade MOX (as fabricated) will be addressed by the MOX Consortium early in the process to confirm that adequate bases exist to confirm the staff preliminary conclusion that there is no risk- issue associated with the use of MOX fuels. In addition, as part of the licensing reviews, the staff expects the MOX Consortium will address the concern related to the residual effects of gallium on fuel rod cladding behavior under transient and accident conditions.

The inhomogeneities (plutonium clusters) in MOX fuel may affect fuel behavior during a reactivity-initiated accident. The NRC is negotiating for participation in the Cabri (France) and in NSRR (Japan) to obtain relevant reactivity insertion accident data for tests performed on MOX fuel, as well as reviewing the data base to address the plutonium inhomogeneities issue.

(c) Source Terms

The staff believes that the gap release (source term) may increase (marginally) because of the elevated operating temperatures in MOX fuel compared with UO_2 fuel. The gap release is used in the analysis of design basis accidents, but it will not have a large effect on severe accident source terms. Because of the way MOX is fabricated, MOX porosity may be different from uranium-based fuel porosity. The difference in porosity could result in higher releases of volatile radionuclides during the early stages of core degradation. However, it is not likely that severe accident progression, insofar as the staff understands it, would be significantly different. Hence, consequence analyses, rather than full probabilistic risk assessments, may be sufficient to assess the risk associated with the use of MOX fuel.

To address the above issue, the NRC will benchmark the FRAPCON code against data from the NSRR reactor (Japan) and the Halden reactor (Norway). The FRAPCON code will be used to estimate the increase in fission product gas release from the fuel pellet to the gap for both MOX and UO_2 fuel during normal operation. Using the FRAPCON results, the staff plans to perform consequence calculations (e.g., using the RADTRAD code) of design basis accidents (e.g., fuel handling accidents) to confirm the MOX Consortium's assessment of the impact of MOX fuel on offsite consequences.

For severe accident conditions, the NRC will obtain fission product release data from the VERCORS (France) and the VEGA (Japan) tests under the NRC's current Cooperative Severe Accident Research Program. Additional fission product release test data may become available from the MADRAGUE (France) within two to three years. The results from experimental programs will be evaluated to confirm the similarity of MOX and uranium-based fuel with regard to the NUREG-1465 source term and core melt progression. Furthermore, the staff plans to perform analyses using radionuclide inventories for a core containing one-third MOX fuel and for a core containing no MOX fuel to estimate the release to the environment for risk-important accidents. Using these release, the staff plans to perform MACCS code calculations to confirm the MOX Consortium's assessment of the impact of MOX fuel on offsite consequences.

<u>RESOURCES</u>:

The staff estimates that approximately 5 FTE and $6.7 million will be required to complete the research planned for FY 2000 - FY 2004. Of the resources required in FY 2000, 1 FTE is included in the FY 2000 budget and the $0.5 million will be considered as part of the FY 2000 mid-year resource review. The FY 2001 budget request includes only $0.75 million and 1 FTE of the $1.15 million and 1.3 FTE identified for research planned in FY 2001. Reprogramming to accommodate additional funding requirements in FY 2001 and resource requirements for FY 2002 will be addressed in the FY 2002 budget formulation process. Resources needed for FY 2003 and beyond will be addressed in subsequent years. It should be noted that these resource estimates are subject to change as the research progresses, NRC risk-informed activities proceed, interactions occur with the MOX Consortium, and the exact work scope is better determined.

COORDINATION:

The Office of the Chief Financial Officer has reviewed this paper for resource implications and has no objections.

SUMMARY:

The staff has prepared a Program Plan to develop certain capabilities in order to effectively review the use of MOX fuel in commercial nuclear power plants. These efforts address the need for modifying NRC neutronics and fuel codes, obtaining the necessary MOX data needed to confirm these codes, and evaluating the MOX Consortium's assessment of the use of MOX fuel in commercial PWRs. The validation of NRC codes with reactor-grade MOX data will provide the confidence to the staff in using these codes for the analysis of MOX cores. Furthermore, by modeling the exact isotopic composition and impurity (gallium) of the weapons-grade plutonium the difference between reactor-grade and weapons-grade MOX can be taken into account in the NRC codes modified for MOX analysis. The staff plans to discuss this Program Plan with the Advisory Committee on Reactor Safeguards.

Attachment: As stated

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Attachment: As stated

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ATTACHMENT

PROGRAM PLAN TO RESOLVE SPECIFIC TECHNICAL ISSUES FOR MOX FUEL

This Program Plan describes the NRC's confirmatory research that is planned for the near future to enable the staff to develop certain independent capabilities in order to effectively review a MOX core license application. The specific technical issues related to the utilization of MOX fuel and the NRC research to address these issues are outlined in this attachment. The RES staff intends to expand the scope of the current expert panel on high burnup fuel issues as needed to address specific new issues that might arise related to MOX fuel.

1. <u>Reactor Physics</u>

1.1 Issue - Difference Between MOX and Uranium Fuels

The neutron energy spectra of MOX fuel assemblies is hardened compared to that of uranium fuel assemblies. This effect, coupled with the differences in the cross-sections of plutonium and uranium, can lead to large gradients in the neutron energy spectrum as well as thermal flux between the two types of fuel assemblies. The differences in cross-sections between plutonium and uranium also lead to changes in the Doppler (fuel temperature) coefficient, the moderator temperature coefficient, and void coefficient. The energy released per plutonium fission is higher than per uranium fission, and the early decrease in decay heat for MOX fuel would lead to differences under accident conditions. Core design and safety analysis will have to take these differences into account.

NRC Research

The NRC neutronics code will be upgraded to include MOX-specific models. Some of the most critical models that need to be added to the neutronics code include multiple energy groups with up scatter, capability to capture the steep gradients between the two types of fuel assemblies, improved delayed-neutron precursor calculations, a revised decay heat model, and a method to handle local power peaking. In addition, the NRC will acquire the capability (i.e., appropriate lattice physics code) to independently calculate MOX cross-sections for input to the neutronics code.

After the NRC neutronics code is modified, it will be necessary to validate it against relevant data. For reactor-grade MOX fuel, NRC will obtain data from the Halden reactor in Norway and the Organization for Economic Cooperation and Development (OECD). Startup and operational data from representative European power reactors that use MOX fuel will be useful for code validation. As part of the licensing reviews, the staff expects that the MOX Consortium will provide these data in support of its licensing case, and the data will then be available to the NRC for code validation. RES will work with NRR and the MOX Consortium to obtain the data from the lead test assembly program which the staff needs for the validation of the NRC neutronics code for weapons-grade MOX.

1.2 Issue - Reduced Control Rod Worth

Control rod worth is reduced by MOX fuel because the increased thermal neutron cross-section of plutonium allows the fuel to compete more effectively with the control rod materials. This can reduce reactor shut-down margins. Coupled with a lower delayed neutron fraction (beta value) of MOX fuel, the use of MOX fuel will lead to different reactivity insertion scenarios.

NRC Research

The data NRC obtains from the Halden reactor in Norway, the OECD, and especially the startup and operational data from representative European power reactors using MOX fuel will be used to assist in the evaluation of the shut-down margins for MOX cores. The change in the severity of reactivity insertion accidents with MOX will be addressed.

2. Fuel Behavior

2.1 Issue - Differences in MOX Fuel Properties

For a given fuel rod power, MOX fuel rods operate with higher centerline temperatures because of the reduced thermal conductivity of MOX compared with UO_2. This will increase the initial fuel rod stored energy at the beginning of a postulated transient or accident (e.g., a LOCA). In addition, chemical bonding between the pellets and the cladding, which may be different for MOX pellets and UO_2 pellets, may affect the ballooning process and hence the fuel behavior.

NRC Research

NRC fuel codes (FRAPCON, FRAPTRAN) will be modified for MOX fuel to account for altered materials properties such as thermal conductivity, thermal expansion, and creep rates. To validate these fuel codes, NRC will obtain data from the Halden reactor and other programs. The MOX Consortium may have other sources of data and, as part of the licensing reviews, the staff expects that the MOX Consortium will provide data in support of its licensing case. The data will then be available to the NRC for code validation. With the validated codes, the staff plans to assess the impact of the differences in MOX fuel properties on previously analyzed transients. The staff expects that as part of the licensing reviews, information on the difference between reactor-grade and weapons-grade MOX (as fabricated) will be addressed by the MOX Consortium early in the process to confirm that adequate bases exist to confirm NRC's preliminary conclusion that there is no risk- issue associated with the use of MOX fuels. In addition, as part of the licensing reviews, NRC expects the MOX Consortium will address the concern related to the residual effects of gallium on fuel rod cladding behavior under transient and accident conditions.

2.2 Issue - Inhomogeneous Plutonium Clusters in MOX Fuel

Inhomogeneous plutonium clusters in MOX fuel may affect fuel behavior during reactivity-initiated accidents. These plutonium clusters are formed during the MOX pellets' fabrication, which is similar to the fabrication process used in Europe. In particular, mechanically blending UO_2 and PuO_2 powders, then pressing and sintering them, results in a ceramic that is not homogeneous on a microscopic scale, and the little islands of high plutonium concentration act as hot spots because of their high fissile content.

NRC Research

NRC is negotiating for participation in the Cabri program with the Institut de Protection et de Surete Nucleaire (IPSN) of France, and in the NSRR program with the Japan Atomic Energy Research Institute. NRC will review the data base to address the issue. When significant test results from the Cabri and NSRR test reactor become available (3 to 5 years), the data will be used by the staff to confirm the MOX Consortium's assessment of the acceptability of MOX fuel.

3. Source Terms

3.1 Issue - Difference in Fission Product Gap Inventory

For a given fuel rod power, MOX fuel rods operate with higher centerline temperatures because of the reduced thermal conductivity of MOX compared with UO_2 fuel. Higher temperatures also increase gas release from fuel pellets and, hence, the fission product gap inventory.

NRC Research

The related gap activity may impact some offsite dose calculations. The staff will obtain the data on fission gas release under normal reactor operational conditions for MOX from the NSRR test reactor and the Halden reactor to benchmark the FRAPCON code. The staff plans to use the FRAPCON code to estimate the increase in fission product gas release from the fuel pellet to the gap for both MOX and uranium-based fuel during normal operation. Using the FRAPCON results, the staff plans to perform consequence calculations using the RADTRAD code to evaluate the impact of MOX fuel on offsite consequences.

3.2 Issue - NUREG-1465 Source Terms and Radionuclide Inventory

Because of the way MOX is fabricated (mechanical blending of UO_2 and PuO_2 powders, followed by pressing and sintering), the porosity of MOX may be different from uranium-based fuel porosity. It has been suggested that the different porosity could result in higher releases of volatile radionuclides during the early stages of core degradation.

At any given time, MOX fuel will have more plutonium than UO_2 fuel, and the inventory of other actinides and fission products will also be somewhat different. In particular, higher actinide inventories will be available. Hence, this could affect the consequences of a severe accident.

NRC Research and Analysis

For severe accident conditions, the staff plans to obtain the fission product release data from VERCORS experiment in France and VEGA experiment in Japan through the NRC's Cooperative Severe Accident Research Program. Additional fission product release data may become available from the MAGRAGUE experiment in France within two to three years. The results from these experimental programs will be evaluated to confirm the similarity of MOX and uranium-based fuel with regard to the NUREG-1465 source terms.

The staff plans to perform analyses using radionuclide inventories for a core containing one-third MOX fuel and for a core containing no MOX fuel to estimate the release to the environment for risk-important accidents. Using these release, MACCS code calculations will be performed to evaluate the impact of MOX fuel on offsite consequences.

MOX FUEL RESEARCH SCHEDULES

1. Reactor Physics

FY 2000 | FY2001 | FY 2002 | FY2003 | FY2004

PIRT

Modify neutronics code. Assess code with appropriate data (e.g., Halden reactor, Consortium MOX lead test assembly, Plant startup/operational data).

In-House Assessment and Analysis as Needed

2. Fuel Behavior

FY 2000 | FY2001 | FY 2002 | FY2003 | FY2004

PIRT

Modify codes (FRAPCON, FRAPTRAN). Assess codes with appropriate data (e.g., Halden reactor, Consortium MOX lead test assembly).

CABRI (France), NSRR (Japan) Test Data Assessment & Code Validation

Cooperative Research with DOE

In-House Assessment and Analysis as Needed

MOX FUEL RESEARCH SCHEDULES

3. Source Terms