Independent Oversight Inspection of Reinforced Concrete Construction at the

Savannah River Site Mixed Oxide Fuel Fabrication Facility

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Office of Independent Oversight
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Abbreviations Used in This Report

ACI	*American Concrete Institute*
ASME	*American Society of Mechanical Engineers*
ASTM	*American Society for Testing and Materials*
CFR	*Code of Federal Regulations*
CR	*Condition Report*
DOE	*U.S. Department of Energy*
ECR	*Engineering Change Request*
MFFF	*Mixed Oxide Fuel Fabrication Facility*
MOX	*Mixed Oxide*
MOX Services	*Shaw/AREVA MOX Services, LLC*
NCR	*Nonconformance Report*
NNSA	*National Nuclear Security Administration*
NRC	*Nuclear Regulatory Commission*
NRMCA	*National Ready Mixed Concrete Association*
QA	*Quality Assurance*
QC	*Quality Control*
SC	*Seismic Category*

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1 Introduction

The U.S. Department of Energy (DOE) Office of Independent Oversight conducted a nuclear safety inspection at the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF) construction project, focusing on construction quality, specifically for reinforced concrete, at the MFFF construction project. This purpose of the inspection was to provide mission support to site management in determining whether the facility structure is constructed in accordance with the applicable requirements.

Design and construction of the MFFF is being performed by Shaw/AREVA MOX Services, LLC (MOX Services), under contract to DOE. The MFFF is being licensed by the U. S. Nuclear Regulatory Commission (NRC) under Title 10 Code of Federal Regulations Part 70 (10 CFR 70). MOX Services submitted a Construction Authorization Request for the MFFF to the NRC in 2001, and the NRC issued a construction authorization for the MFFF on March 30, 2005. The codes and standards for design and construction of the project are specified in an updated license application submitted by MOX Services to NRC on December 17, 2007. The National Nuclear Security Administration (NNSA) provides onsite project management for DOE through its MOX Integrated Project Division (NA-265).

In 2000, the United States and Russia agreed to dispose of 34 tons of weapon-grade plutonium each – enough for thousands of nuclear weapons. DOE is constructing three facilities at the Savannah River Site to dispose of 34 tons of U.S. plutonium by converting it into fuel for nuclear power reactors: the Pit Disassembly and Conversion Facility, the MFFF (the subject of this inspection), and a Waste Solidification Building. Russia plans to build a MOX fuel fabrication facility to convert an equivalent amount of plutonium from its weapons stockpile into reactor fuel.

MOX Services estimates that the design of MFFF is 85 percent complete and construction is 19 percent complete. Current construction activities are primarily civil/structural in nature. The basemat is complete, and Seismic Category 1 (SC-1) reinforced concrete walls are being constructed. Structural steel work at the time of this inspection was limited to installation of equipment supports, structural plates embedded in concrete, and door frames. At the time of inspection, approximately 54,000 cubic yards of reinforced concrete had been placed.

Construction Activities at MOX

Considering the status of construction activities, this Independent Oversight inspection focused on the manufacture, testing, and placement of concrete and installation of reinforcing steel in SC-1 interior walls of the MFFF. Construction activities were observed, workers and managers were interviewed, and records and procedures were reviewed to assess the quality of MFFF construction.

Sections 2 and 3 of this report discuss the key positive attributes and weaknesses, respectively, identified during this inspection. Section 4 presents the results of the Independent Oversight assessment of the manufacture, testing, and placement of reinforced concrete and related activities performed by MOX Services and its subcontractors. Independent Oversight's conclusions regarding the quality of reinforced concrete construction at the MFFF are presented in Section 5, and opportunities for improvement for consideration by NNSA and MOX Services are presented in Section 6. Appendix A provides supplemental information, including team composition.

Appendix B presents a finding identified during this Independent Oversight inspection. The finding is also referenced in the applicable portions of Sections 3 and 4 of this report. NNSA, the NNSA Savannah River Site Office, and MOX Services are responsible for ensuring that corrective action plans are developed to address the finding identified in Appendix B and other deficiencies identified in this report as appropriate, in accordance with the appropriate site issues management processes and quality assurance (QA) requirements.

2 Positive Attributes

Positive attributes were identified in key areas of reinforced concrete construction at MFFF, including concrete manufacturing and placement and most aspects of quality control (QC) inspections.

Most aspects of concrete manufacturing and placement meet or exceed construction specifications and industry standards. Materials used by MOX Services for the manufacture of concrete are properly qualified, are traceable to approved sources, and meet specification requirements. Onsite concrete batch plants are in good condition and have the capacity to meet MFFF construction needs. The plants have been inspected by a professional engineer and certified to National Ready Mixed Concrete Association (NRMCA) standards. Storage and handling of concrete ingredients are properly controlled. Concrete transporting trucks are also in good condition and are certified to NRMCA standards. Observed concrete pre-placement activities, including installation of rebar and forms, were properly performed. Challenges with rebar installation (e.g., space restrictions, design deficiencies, and procurement problems) are being effectively addressed, and rebar inspected by Independent Oversight was properly installed. Concrete placement activities, including concrete consolidation, were also properly performed.

The QC inspections performed before and during placement were thorough. Mutual respect and good communications are evident between craft workers and QC inspectors. The QC inspectors demonstrated a good understanding of project requirements and the ability to read and understand construction drawings. Inspection activities and identified deficiencies were properly documented in permanent plant records. QC inspectors, testing technicians, and craft workers involved with the observed placements had received appropriate training. Observed concrete testing met American Society for Testing and Materials (ASTM) standards. Testing equipment was calibrated, personnel conducting tests were qualified, and test techniques met applicable standards. The concrete was sampled at the proper frequency for determining temperature, slump, air content, and unit weight. Test results show that essentially all concrete placed to date has met specification requirements for temperature, slump, and strength. Concrete strength tests show that 99 percent of the concrete placed to date in safety class structures met design compressive strength requirements.

Construction Activities at MOX

3 Weaknesses

Weaknesses were identified in several aspects of reinforced concrete construction at MFFF, including controls for air entrainment in concrete and some aspects of design engineering activities.

Controls over entrained air in concrete have not been sufficient to ensure consistent compliance with MOX Services Concrete Specification Section 03051, *Mixing and Delivering for Quality Level QL-1a (IROFS) and QL-2 Concrete*. Until recently, samples for in-process testing of pumped concrete were collected at the point of delivery (i.e., at the back of the delivery truck) but were not consistently collected at the point of placement (i.e., discharge of the pumper hose) as specified by American Society of Mechanical Engineers (ASME) NQA-1, Quality Assurance Requirements for Nuclear Facility Construction. The air content in samples from the point of delivery was not representative of the air content at the point of placement, so test results did not provide a reliable indication of the air content of concrete placed in the plant. Independent Oversight observed placement of concrete that did not meet specifications for entrained air, and MOX Services QC inspectors identified numerous previous placements that did not meet these specifications. Placements continued even after test results that the indicated air content at the point of placement did not meet specifications. Most of these deficiencies involved the placement of concrete that contained less air than specified by applicable specifications, thus increasing the susceptibility of the cured concrete to damage by freezing weather. The impact of low entrained air on concrete that has been placed in the MFFF is mitigated by the fact that all concrete placed to date has been in the interior walls and the below-grade basemat, none of which will likely be exposed to freezing weather in the moderate climate of Aiken, South Carolina, once construction is complete. Nonetheless, increased rigor in the control of entrained air will be needed to ensure the durability of concrete to be placed in the exterior walls and roof. (See Finding #1.)

Design engineering has not always provided sufficiently detailed technical justifications on nonconformance reports (NCRs) for using out-of-specification concrete. For example, engineering has typically dispositioned NCRs written on insufficient entrained air by stating "use as is" based on strength test results without discussing the potential loss of durability due to freezing weather, and without identifying the cause of these recurring deficiencies or specifying actions to preclude recurrence. Similarly, the documented technical justifications provided by design engineering on NCRs that accepted the use of concrete with below-specification slump test results reference only the cylinder strength test results. Low slump reduces workability and can produce voids in concrete during placement, but the technical justification for "use as is" that was provided on NCRs by design engineering did not address the potential for voids. In another case, an NCR that was written because of low concrete strength did not address the fact that the unit weight of the concrete was on the low end of the acceptable range. Collectively, these examples indicate the need to improve documentation of engineering analyses and the basis for acceptance of nonconforming conditions. Design engineering is aware of the need to improve technical justifications and has recently trained engineers to improve performance in this area.

Design engineering has not documented the review of facility settlement data or the review and documentation of changes in concrete construction joint locations. Periodic review of settlement data is important for identifying facility settling that can produce structural cracks and damage to infrastructure, such as buried piping and duct banks. MOX Services has implemented a comprehensive settlement monitoring program for SC-I structures. Design engineering collects settlement data for analysis, but assessment of this data has not been systematically performed or documented. Construction joints are being placed in locations different from those shown on design drawings without a documented engineering analysis of the change. Design engineering explained that calculations performed pursuant to America Concrete Institute (ACI)-349 would show that the joints had strengths equal to the original design and that the shear strength of the rebar alone would be sufficient to sustain design basis loads. However, neither a bounding calculation nor calculations for specific joints were included in the design documentation for the facility.

4 Results

4.1 Concrete Manufacturing

Independent Oversight confirmed that materials used for manufacture of concrete are properly qualified, are traceable to approved sources, and meet specification requirements. Concrete ingredients are classified as Quality Level 1a and are procured from suppliers with approved QA programs. Approved suppliers submit certified material test reports to demonstrate that materials they provide comply with project requirements. Independent Oversight reviewed these reports, which document the results of tests performed by suppliers of cement, fly ash, and chemical additives (admixtures). Independent Oversight also reviewed results of tests performed by independent laboratories on sand and gravel, and on the site water used to mix batches of concrete. The test results were compared with acceptance criteria specified in ACI-349-97, *Code Requirements for Nuclear Safety Related Concrete Structures*, ACI 301-99, *Standard Specifications for Structural Concrete,* and MOX Services specifications to confirm that the quality of the ingredients met applicable criteria. Independent Oversight did not identify deficiencies in these processes.

Onsite concrete batch plants are in good condition and have the capacity to meet MFFF construction needs. The concrete is manufactured and supplied by MOX Services from two batch plants on the MFFF site. One plant would provide sufficient capacity to meet concrete demands, but the second plant provides backup in case of a malfunction of the primary batch plant during a concrete placement so that the placement can be continued without interruption. A diesel generator serves as a backup power supply in case of loss of offsite power during a placement.

In hot weather, the batch water is cooled by a chiller unit, and ice is added as necessary to further reduce concrete temperatures. The ice is shipped to the site in plastic bags, which are stored in a large freezer and weighed prior to addition to the mix. A water heating facility is in place to maintain concrete temperature within specifications during cold weather.

Moisture probes continuously monitor the moisture content of concrete aggregate and adjust the quantity of mix water to account for the free water in the aggregate. The moisture probes are calibrated daily by a concrete laboratory technician certified by the ACI from an independent testing laboratory, (i.e., QORE).

The concrete batch plants have been inspected by a professional engineer and certified to NRMCA standards. Calibration of scales and meters met or exceeded frequency requirements and results were within specified tolerances. Concrete transporting trucks are in good condition and certified to NRMCA standards.

Storage and handling of materials are controlled. Mixer efficiency tests are performed in accordance with ASTM C-94, at the proper intervals. Cement and fly ash are protected from moisture, aggregates are segregated by size and protected from contamination, and admixtures are prevented from freezing. Materials are proportioned in quantities determined by concrete mix designs. The mix designs are based on securing a workable mixture with the specified design strength within the specified ranges of entrained air and slump. Test results showed that the design mixes met the design requirements for compressive strength, slump, entrained air, and unit weight. New mix designs are proportioned and tested when the sources of concrete materials or the mix properties are changed.

Batch records are generated and controlled, and they indicate placement location, mix, weight/volume of ingredients, batch volume, date, batch time, water-cement ratio, and quantity of water withheld. An ACI certified concrete technician from QORE, the independent testing laboratory, tests the initial batches of the concrete at the batch plant to verify that the concrete meets specification requirements for placement in the project. These tests are performed for information only, and the results are not documented. The QORE technician also performs moisture and gradations tests on the concrete aggregates.

One deficiency was noted in evaluation of the concrete mixes. The total chloride content of the concrete mix, contributed from all mix ingredients, was not determined as recommended in ACI-301 and ACI-349. The purpose of determining the chloride content is to ensure that the concrete reinforcing steel will not be subjected to corrosion by chlorides present in the hardened concrete.

4.2 Concrete Testing

The testing that Independent Oversight observed was conducted in accordance with ASTM standards. QORE technicians receive concrete from each delivery truck and review the concrete batch ticket to ensure that the proper concrete mix is being delivered. QORE technicians perform QC testing of the concrete. The technicians sample and test the concrete for determination of temperature, slump, and unit weight, and they mold cylinders for concrete strength testing. The results of these tests are recorded on the QORE concrete placement log, which also lists the acceptance criteria for the concrete mix being placed.

MOX Services QC inspectors review the in-process test data, review the batch tickets, and verify that concrete is discharged from the delivery truck within the maximum allowable time of 90 minutes. They also verify that the truck mixer drum does not exceed a total of 300 revolutions. The inspectors have the authority to reject concrete batches not meeting specification requirements.

Independent Oversight reviewed the concrete batch tickets and witnessed testing of the freshly mixed concrete being placed in several placements. The concrete was sampled at the proper frequency for determination of temperature, slump, air content, and unit weight. Sample collection and testing techniques conformed to the procedures specified in applicable ASTM standards. Samples for air entrained in pumped concrete were obtained from the end of the pump line, at the point of placement. Test cylinders for concrete strength testing were also collected from the point of placement and were prepared at the required frequency. Cylinders were molded and stored in curing boxes for the first 24 hours, in accordance with the requirements of ASTM C-31. Testing equipment used to perform onsite testing of materials and freshly mixed concrete was calibrated. Personnel performing sampling and testing of concrete were qualified. However, as discussed below, responsibilities are not clearly assigned or understood for actions to be taken when in-process test results do not meet specifications.

Test results show that essentially all concrete placed to date has met specification requirements for temperature, slump and strength. A review of test results for concrete placed from October 10, 2007, through August 11, 2009, indicates that all of the concrete met temperature specifications, and 98 percent of the results were within the allowable range for slump. Results of compressive strength tests performed on concrete cylinders have also been within specifications, with very few exceptions; 99 percent of the samples tested during this period met or exceeded strength requirements. NCRs were written and evaluations were completed when specifications were not met, although as discussed below, technical justifications were not always adequately documented.

Concrete placed in the basemat and interior walls has not always met MOX Services specifications for entrained air. The MOX Services Construction Specification Section 03051, *Mixing and Delivering for Quality Level QL-1a (IROFS) and QL-2 Concrete,* specifies minimum and maximum air concentrations for each concrete design mix. Maintaining the air concentration at or above the minimum value is important for ensuring the durability of concrete exposed to freezing weather, and maintaining air at or below the maximum is important for ensuring that the concrete meets strength requirements. In-process sampling and testing conducted during concrete placement indicates that the concentration of entrained air has been below the specified minimum for several placements in the MFFF basemat and interior walls. For example, concrete containing 2.0 percent air, which was placed at location BMP W124A.3.1 on August 18, 2009, was outside of the 4 to 8 percent allowable range specified by the MOX concrete specification for the mix (i.e., design mix C) being placed. Similarly, concrete with an air content of 2.2 percent, which was placed at location BSR-F101A on August 21, 2009, was not within the 3.5 to 6.5 percent allowable range specified by the MOX concrete specification for the design mix (design mix B) being placed at that location. (See Finding #1.)

The placement of concrete not meeting specification-defined limits for entrained air has been a longstanding problem. NCR Number QC-08-0397, issued in July 2008, documented 19 examples of placements that did not meet the MOX concrete specification criteria for entrained air. This NCR and other NCRs were closed with the justification that there was no adverse effect on the compressive strength of the concrete. The principal reason for adding air to concrete is to improve freeze protection. Most NCRs did not address freeze protection and did not address the cause or solution for the out-of-specification concrete. The significance of this deficiency is mitigated by the fact that concrete has not yet been poured in the exterior walls or roof and by the fact that the interior walls and basemat are not expected to be exposed to freeze-thaw weather conditions once construction is completed. Nonetheless, performance to date indicates the need for increased rigor in the control of entrained air to ensure compliance with applicable concrete specifications and industry standards. (See Finding #1.)

Most previous samples that were tested for entrained air were not collected at the point of placement or correlation tested as required by ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Construction, and the concentration of air in these samples was not representative of the entrained air in concrete placed in the plant. ASME NQA-1, Subpart 2.5, Section 7.11 (which was a requirement in the MOX Services QA program until June 15, 2009, when NRC approved an exemption to this requirement) states in part that "When concrete is pumped during its movement from the delivery point to the placement point, in-process strength samples shall be taken at the placement point unless correlation tests of air content, slump and temperature are performed." The failure to perform correlation testing was initially identified by QC and QA personnel and documented in Condition Report (CR) 20080143 in April 2008. However, the MOX concrete specification was not revised to address this issue. Prior to the issuance of Engineering Change Request (ECR) 003068 on June 30, 2009, the MOX concrete specification did not require strength samples of pumped concrete to be taken at the point of placement, and formal correlation tests of air content, slump, and temperature were not performed. ECR 003068 was issued as part of the corrective actions to address voids and concrete defects documented on CR 20090007. (See Finding #1.)

Samples of record are now being collected at the point of placement, and, although not required by the concrete specification, samples are also being collected at the point of delivery (i.e. at the discharge of the delivery truck). The point-of-delivery samples are analyzed "for information only" for air and slump. No requirement has been established for correlation testing of pumped concrete to ensure that concrete placed in the MFFF meets the acceptance criteria in MOX Services concrete specifications.

Construction Activities at MOX

Data provided to Independent Oversight show a close correlation in slump test results for samples taken before and after concrete pumping. However, the data indicate an average loss of entrained air of about 18 percent during pumping. At the time of this inspection, MOX Services had not identified the cause of this loss of air and had not established entrained air acceptance criteria, based on a correlation of sample test results, to be applied to concrete before it is pumped to ensure that it will meet specifications after it is placed in the forms. (See Finding #1.)

In September 2008, MOX Services engineering inappropriately deleted the concrete specification requirement for entrained air testing for concrete to be placed in interior walls. No change was made to mix designs, which required admixtures for entraining air, and thus the change created a potential for undetected excessive entrained air that could reduce concrete strength. No change was made to concrete specifications, which specified acceptance criteria (minimum and maximum percentages) for entrained air. Although not required by the specifications, at the direction of MOX Services QC, QORE technicians continued to test the fresh concrete for entrained air content. (See Finding #1.)

Responsibilities are not clearly assigned for accepting or rejecting concrete when test results obtained during placement do not meet acceptance criteria. When concrete samples are collected at the point of placement, the pumping of concrete into forms continues while the samples are analyzed. This pumping has continued, without engineering evaluation, even after test results indicate that the concrete being placed in interior walls does not meet specifications for entrained air. The MOX concrete specification identifies minimum and maximum air concentrations for concrete mix designs but does not assign responsibility or specify action to be taken when sample testing during placement fails to meet these criteria. Some QC inspectors and craft personnel misinterpreted the deletion of the air testing requirement from concrete specifications to mean that the entrained air criteria no longer had to be met. A concrete placement inspection report form is completed by MOX Services QC. QORE technicians record the results of the tests performed on the freshly mixed concrete on a form titled "QORE Concrete Placement Log." For a period of time in early 2009, the QORE inspection form did not list acceptance criteria for entrained air testing; the form listed "N/A" for entrained air test acceptance criteria. (See Finding #1.)

MOX Services has produced concrete at its batch plant with more entrained air than allowed by plant operating procedures to compensate for air losses during delivery and pumping and to meet specifications at the point of placement. Procedure PP11-3, *Batch Plant Operating Instructions*, Revision 0, requires the first batch from a scheduled load to pass a test for temperature, slump, and air content. On August 20, 2009, MOX Services produced concrete at the batch plant containing 9 percent air when the concrete specification required 4 to 8 percent for design mix C. The concentration after delivery and pumping was within specifications. Records of this batch plant testing are not retained, so Independent Oversight was not able to assess how often the test results did not meet specifications. (See Finding #1.)

In summary, controls over entrained air in concrete have not been adequate to ensure consistent compliance with concrete specifications. The impact of this deficiency is mitigated by the fact that all concrete placed to date has been in the interior walls and below-grade basemat, which will not likely be exposed to freezing weather in the moderate climate of Aiken, South Carolina. Independent Oversight also noted some inconsistent results for concrete unit weight measurements that had not been evaluated to determine possible reasons for the variations, which could possibly be attributed to control of entrained air. Increased rigor in the control of entrained air will be needed to ensure the durability of concrete to be placed in the exterior walls and roof. (See Finding #1.)

4.3 Concrete Placement

Concrete placement operations were adequate for observed wall placement number BMP W124A.3.1. The equipment to deliver concrete to the placement locations was in good condition.

Pre-placement planning and training was completed to ensure good-quality construction and to protect against unplanned construction joints. Sufficient concrete vibrators were on hand, with extras on standby, for consolidating concrete. Preparations for curing and protection from rain were completed before the start of concrete placement. The placements were cleaned and joint preparation was as specified in the construction specification. Forms were secure, leak-proof, and free from standing water. QC pre-placement inspections were thorough and completed before any concrete was placed. Pre-placement planning completed by construction ensured good-quality construction. There was sufficient access to the placement locations for vibrator operators and other craftsmen, concrete placement equipment, and QC inspectors.

Concrete placement drop distances were within specification requirements. Vibrators were properly used, were not used to move concrete excessive distances, and were operated by trained individuals. Special attention was given to areas where reinforcing steel was congested. Excess water did not accumulate in the forms during placement. Activities associated with concrete placements were well controlled, with the exception of lack of clear acceptance criteria regarding handling of concrete when entrained air content falls below specification limits, as discussed above.

Concrete batch tickets were reviewed by QC for verification of proper mix and placement location. The amount of water withheld from the batch was recorded on the batch ticket. The time limit between mixing and delivery was not exceeded, and the total number of revolutions of the truck mixer did not exceed the limit of 300 specified in ASTM C-94. Specification temperature limits were met.

MOX Services QC performs adequate inspection of structural concrete construction operations. QC inspectors are involved in all aspects of structural concrete activities and are required to inspect and accept each activity. Mutual respect and good communications were evident between craft workers and QC inspectors. Inspection hold points are specified for each activity. These included pre-placement activities, such as concrete forms, rebar installation, and cleanliness inspections; concrete placement activities, including in-process testing of plastic concrete and concrete consolidation; and post-placement inspections, such as concrete curing and form removal. All inspection activities are documented for each concrete placement on a record designated as the “Concrete Pour Card,” with the exception of tests performed on concrete, which are documented on the QORE concrete placement log.

Strength tests showed that concrete placed to date, with few exceptions, met design requirements. In the few cases where tests indicated that concrete did not meet design specification strengths, NCRs were initiated and dispositioned in accordance with the MOX Services QA plan and ACI standards, although some technical justifications for use-as-is dispositions were not adequately documented.

Concrete test and inspection personnel were qualified to perform their assigned tasks. Review of training and certification records for three MOX Services QC inspectors and six concrete testing technicians employed by QORE indicated that each individual was appropriately qualified. The QORE technicians were certified by ACI.

Independent Oversight reviewed the QA audits performed by MOX Services to qualify QORE to perform testing of the QL-1a concrete and materials for the MOX project. The audits were detailed and thorough. Audit findings were documented, and corrective actions were verified before QORE started work on the project. Independent Oversight also reviewed the ongoing periodic QA surveillances performed by MOX Services on QORE, which demonstrated continuing compliance with the QORE QA program.

Records documenting placement and inspection of concrete are adequate. However, the electronic database in which these records are stored (i.e., Documentum) is poorly indexed and cross referenced. For example, the results of in-process testing performed on fresh concrete by QORE are for the most part entered into the Documentum system as QORE concrete placement reports. Results of concrete cylinder unconfined compressive tests are entered as cylinder break reports. The records are not always entered in chronological order and do not identify a particular concrete placement or date in the title. Therefore, it is difficult to retrieve a record for a specific concrete placement or date. Records from Baker Construction and other organizations (e.g., the URS Washington Group, which tests rebar splices) also do not show adequate identifying information in the index or records log. Records for cutting rebar may be difficult to retrieve as well. These records are currently retained in document files, known as work packages, for each concrete placement. These record packages are voluminous and are sometimes not well organized.

4.4 Reinforcing Steel (Rebar) and Embedded Plates

Adequate controls are in place to ensure that concrete reinforcing steel (rebar), embedded plates, and penetrations (blockouts) are installed in accordance with design drawing and specification requirements and are inspected and accepted prior to placement of concrete. Design and field changes are controlled and incorporated in the work packages used by construction craft and QC inspection personnel. The QC inspectors who were interviewed were knowledgeable of quality requirements, and they demonstrated a good understanding of project requirements and their ability to interpret drawings and specifications.

Based on limited observations, reinforcing steel, embedded plates, and blockouts are being installed in accordance with specifications, drawings, and procedures. Reinforcing steel size, spacing, lap, and splices were located properly within the forms, were secured and clean (i.e., free from oil, paint, weak dried mortar, dried mud, loose rust, etc.) and had proper clearances. Laydown areas where rebar and embedded plates are stored onsite prior to installation are well maintained. The materials are supported on timber cribbing as required by NQA-1 so they are not in contact with the ground. All items are tagged to show they were receipt-inspected and meet specification requirements.

4.5 Construction Joints

On December 31, 2008, CR 20080502 was written to identify that vertical rebar had been left out of a concrete pour due to relocation of a construction joint. The problem was caused by movement of the construction joint without adequate consideration of all factors involved in the move. A general note on the construction drawing stated that construction joints were considered optional and that the construction contractor could move, change, or delete construction joints shown on the drawings, or add new joints, without engineering approval. Corrective actions to resolve this problem included revising the note, developing a checklist for engineering personnel identifying items that must be evaluated for construction joint changes, and issuing a memo to ensure that engineering personnel clearly understand questions from construction prior to initiating corrective actions.

The CR documentation did not clearly specify whether the problem was caused by an inadequate engineering review of the construction joint change. Revision 3, and the current revision, Revision 4, dated August 14, 2008, of Construction Specification Section 03301, *Placing Concrete and Reinforcing Steel*, required design approval of changes to construction joints shown on the design drawings, or addition of joints. ECR 2023 was issued on March 5, 2009, to revise the general note on the drawing to state: “Movement or deletion of construction joints shown on design drawings require a review and approval by design engineering prior to the concrete pour affecting that joint. Additional joints (not shown on design drawings) may be added by construction without design review as required to accommodate the capacity of the batch plant and efficient placement of the concrete.”

Engineering approval of all construction joints is specifically required by ACI-349-97. After Independent Oversight questioned the practice of permitting addition of new construction joints without engineering approval, the note was revised again in August 2009, to require engineering approval of all construction joint location changes or additions to comply with ACI 349-97 requirements. The drawing note now agrees with Specification Section 03301.

The checklist for construction joint changes was documented in a memorandum to civil engineering design engineers dated March 5, 2009. Items in the checklist included consideration of the effect of construction joint changes on rebar, rebar splices, penetrations in walls/slabs, intersecting walls and slabs, embedded plates, and the design integrity of the structure.

The process for approval of construction joint changes or additions is for the subcontractor, Baker Construction, to submit the request for approval on a Vendor Review Form (traveler) to design engineering. This process has been in use since at least mid-2008. The proposed construction joint revision is reviewed by the design organization. Documentation approving construction joint changes does not specify whether the effect of the relocated or added construction joint on the design integrity of the structure was evaluated as part of the engineering review process; documentation on some travelers only noted hardware (rebar, embeds, etc.) affected by the construction joint change, while other travelers were only marked “approved.”

The approved Vendor Review Forms and attachments are included in affected work packages. The current MOX Services process does not require that design drawings and other design documents be updated to include changes approved via the Vendor Review Form, including construction joints that have been added or relocated by construction.

MOX Services considers relocation of construction joints shown on design drawings to be design changes and processes them in accordance with a formal design change process. However, when joints are added, in addition to those shown on drawings, the additions are typically reviewed by a single engineer, in accordance with a checklist provided by the March 5, 2009, memorandum to civil engineering design engineers. Design engineering explained that the addition and relocation of construction joints do not reduce the design strength of facility structures because (1) shear forces in the structure are essentially carried by the rebar alone and (2) transfer of shear at construction joints is not dependent on shear friction. Nevertheless, the design engineers stated that they follow the provisions of ACI-349 when evaluating the structure for shear capacity. The engineering review of joints does not normally include a calculation of the joint strength, and there is no documented bounding analysis to show that shear transfer capacity at construction joints has been retained. NQA-1, Supplement 3S-1, Supplementary Requirements for Design Control, Section 3.1, requires that design analysis documents be sufficiently detailed as to purpose, method, assumptions, design input, references, and units such that a person technically qualified in the subject can review and understand the analyses and verify the accuracy of the results without recourse to the originator. This requirement could be met by an analysis of each individual construction joint or could be met by a bounding analysis.

4.6 Settlement

MOX Services has implemented a comprehensive settlement monitoring program for SC-I structures. However, the settlement data is not systematically evaluated by engineering, and evaluation results have not been documented.

MOX Services has committed to performance of settlement monitoring and evaluation of actual versus structure settlement in its December 2007 license application to NRC. Independent Oversight reviewed Specification Section 02211, *Settlement Monitoring Program*, MOX Services Procedure PP11-41, *Construction Surveying*, and drawings showing locations and details of settlement monuments. Settlement readings have been taken on a weekly basis since the start of construction. The settlement data is maintained in the QA records system database, Documentum. No inconsistencies were identified by Independent Oversight in the data collected to date. Occasionally, some settlement readings cannot be obtained because one or more monuments are obstructed by construction activities. This information is noted on the data sheets.

Discussions with engineering disclosed they do not have a procedure or program that requires review of the settlement data. Engineering managers indicated that data is reviewed when deemed necessary, but the reviews are not performed periodically and are not documented as required by NQA-1. If settlement data is not reviewed on a consistent, periodic basis, errors in data will not be detected in a timely manner, trends that could affect planned construction activities may not be identified, and actual differential settlement values between structures may not be incorporated in design analyses (for example, in stress analysis for piping which spans between two structures which have experienced differential settlement).

4.7 NCR Responses

Design engineering has not always provided adequate documentation for technical justifications on NCRs for accepting previously placed concrete that did not meet specifications. The justifications provided on several NCRs for low entrained air only considered unconfined compressive strength, not the location of the placed concrete (i.e., interior or exterior wall/slab):

- NCR QC-09-0818, which was written because concrete strength was low, did not address the fact that the unit weight of the concrete was also at the low end of the acceptable range. There is no documentation referenced in the NCR that low unit weight was considered in the evaluation. All other evaluations of low concrete strength reviewed by Independent Oversight were properly documented.

- NCR US-08-0232 accepts concrete with a low slump. The NCR was closed before cylinder tests were completed, although the NRC calls for cylinder tests to be recorded and reported to MOX Services engineering. The technical basis for use-as-is acceptance of the concrete is not documented.

- The technical justification for NCR US-08-0459, use-as-is concrete with low slump, states that low slump had no adverse effects on strength of concrete. A concrete batch with low slump is an indication of less water in the mix, and thus a lower water-cement ratio. Generally, for the same mix, the lower the water-cement ratio, the higher the concrete strength. Therefore, low slump would not adversely affect the concrete strength. However, low slump concrete is more difficult to consolidate and could result in voids in the concrete. The recommended disposition did not call for post placement inspection of the concrete to determine whether there were voids or defects in the concrete. The technical justification should have referenced the results of post placement inspections.

MOX Services recognizes the need to provide better technical justifications on NCRs and has recently provided training to design engineers to improve performance in this area.

5 Conclusions

The overall quality of concrete that has been placed in the MFFF to date is adequate. Essentially all of the concrete met specifications for temperature and slump at the time of placement, and the results of unconfined compression tests performed on cured concrete samples have consistently met or exceeded strength requirements. Placements not meeting specifications were documented on NCRs and dispositioned in accordance with the MOX Services QA program.

Construction Activities at MOX

MOX Services has not controlled the concentration of entrained air with sufficient rigor, and some of the concrete placed in the MFFF may not contain sufficient entrained air to remain durable in freezing weather. However, the concrete placed to date is in interior walls and the basemat, which are not expected to be exposed to freezing conditions once construction is complete. More effective controls will be needed to ensure that concrete placed in exterior walls and roof contains sufficient entrained air for weather protection.

A lack of rigor in the documentation of engineering analyses was also evident. For example, control of entrained air has been a longstanding problem that has not been adequately addressed by design engineering. NCRs, written when concrete test results did not meet specifications, have typically been dispositioned by design engineering stating "use as is." While this disposition may have been appropriate, the technical justifications provided on NCRs are not always adequately documented. Other examples of inadequate documentation include no calculations for shear transfer at construction joints and for design analysis of settlement data.

MOX Services has taken steps to strengthen the support provided by design engineering to MFFF construction. Several engineers have been recently added to the staff, and consultants are being used to assist in the resolution of concrete problems. These recent initiatives can strengthen future performance, but at the time of this inspection, they had not yet been in place long enough to achieve the intended improvements. MOX Services has experienced a high turnover in design engineers since the start of the project, and staffing shortages and inexperience have contributed to a legacy of problems such as those discussed in this report.

6 Opportunities for Improvement

This Independent Oversight assessment identified the following opportunities for improvement to be considered by MOX Services. These potential enhancements are not intended to be prescriptive or mandatory. Rather, they are offered to the site to be reviewed and evaluated by the responsible line management and accepted, rejected, or modified as appropriate, in accordance with site-specific program objectives and priorities.

1. Perform an evaluation of the results of correlation testing of pumped concrete to determine the effect of pumping on entrained air and slump. Based on the results:

    - Revise sampling and testing protocols and controls as necessary to ensure that only concrete meeting acceptance criteria is placed in the MFFF.

    - Ensure that the percentage of entrained air in the placed concrete exposed to weather (exterior walls and roof) meets the recommendations of ACI-301 and ACI-349 for moderate climate exposure at the point of placement.

2. Revise specifications to clearly indicate actions to be taken when in-process test results indicate that concrete that is being pumped into forms does not meet established specifications. Ensure that the concrete trucks are not emptied into the forms before completing in-process test.

3. Establish a program for engineering evaluation of concrete test results (including strength, slump, air content, temperature, and unit weight) to identify trends and potential problems. Ensure that QA/QC data (e.g., a spreadsheet that shows concrete test data for slump, air, and unconfined compression test results) is consistently reviewed by Engineering.

4. Determine the total chlorides in concrete mixes as recommended by ACI-301 and ACI-349.

5. Improve the documentation of design review for changes to construction joint locations or addition of construction joints. Clearly document the technical basis for the assumption that shear transfer in the MFFF structure is provided by the reinforcing steel.

6. Perform a detailed review to verify compliance of MOX Services concrete specifications with ACI-301 and ACI-349.

7. Establish a formal process for systematic engineering evaluation of settlement data.

8. Change the records management process to facilitate retrieval of permanent plant records.

APPENDIX A
Supplemental Information

A.1 Dates of Review

Planning Visit	August 4-6, 2009
Onsite Inspection Visit	August 17-27, 2009
Report Validation and Closeout	September 22-24, 2009

A.2 Review Team Composition

A.2.1 Management

Glenn S. Podonsky, Chief Health, Safety and Security Officer
William Eckroade, Deputy Chief for Operations, Office of Health, Safety and Security
John Boulden, Acting Director, Office of Independent Oversight and Office of Enforcement
Thomas Staker, Director, Office of ES&H Evaluations
William Miller, Deputy Director, Office of ES&H Evaluations
Steven Simonson, Director, Office of Emergency Management Oversight

A.2.2 Quality Review Board

William Eckroade	John Boulden	Thomas Staker	William Miller
George Armstrong	Dean Hickman	Robert Nelson	William Sanders
Pete Turcic			

A.2.3 Review Team

Steven Simonson, SRS Overall Inspection Team Leader
Shiv Seth, Nuclear Safety Team Leader
Al Gibson
Joe Lenahan

A.2.4 Administrative Support

Laura Crampton
Tom Davis

APPENDIX B
Site-Specific Findings

FINDING STATEMENTS	
#1	MOX Services has not controlled the concentration of entrained air in concrete with sufficient rigor to ensure compliance with Construction Specification Section 03051, *Mixing and Delivering for Quality Level QL-1a (IROFS) and QL-2 Concrete*.