UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 9, 2007

MEMORANDUM TO: Alex P. Murray, Senior Chemical Process Engineer
Mixed Oxide Branch
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Materials Safety and Safeguards

FROM: Luis A. Reyes
Executive Director for Operations

SUBJECT: DECISION ON DIFFERING PROFESSIONAL OPINION APPEAL INVOLVING RED OIL EVENTS AT THE MIXED-OXIDE FUEL FABRICATION FACILITY (DPO-2005-002)

The purpose of this memorandum is to inform you of my considerations and conclusions regarding the appeal you submitted on April 18, 2007, on the subject differing professional opinion (DPO).

Introduction -- Red oil is a hydrolysis product that has caused explosions resulting in damage at plutonium purification facilities operated by the U.S. Department of Energy (DOE) and by others in the world. The DPO concerns the adequacy of information in the Nuclear Regulatory Commission (NRC) docketed mixed oxide (MOX) construction authorization request (CAR) submitted for NRC approval in accordance with 10 Code of Federal Regulations (CFR) 70.23(b). A brief description of the MOX plant design bases to prevent/mitigate red oil explosion consequences is provided in Enclosure 1.

Chronology -- On February 28, 2001, Duke, Cogema, Stone, and Webster (DCS), the applicant, submitted a CAR to the NRC for approval to design and construct a MOX fuel fabrication facility on a portion of the DOE Savannah River Site. The CAR, which is required by 10 CFR Part 70, "Domestic Licensing of Special Nuclear Material," continued to be amended and supplemented with information by the applicant until NRC authorized (CAMOX-001) MOX plant construction on March 30, 2005. (Prior to MOX possession of special nuclear material (SNM), 10 CFR Part 70 requires submission and approval of an application for an NRC license to possess SNM.)

The NRC authorization was based on the CAR evaluation documented in NUREG-1821, "Final Safety Evaluation Report on the Construction Authorization Request for the Mixed Oxide Fuel Fabrication Facility at the Savannah River Site, South Carolina." The NRC's Division of Fuel Cycle Safety and Safeguards (FCSS) safety evaluation of the CAR concluded that 10 CFR 70.23(b) requirements were satisfied, i.e., the design basis of the principal structures, systems, and components (PSSC) and the quality assurance program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents.

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In a letter to the NRC Chairman dated February 24, 2005, the Advisory Committee on Reactor Safeguards (ACRS) described its review of the Safety Evaluation Report (SER) and concluded that the information from DCS provided sufficient assurance to proceed with MOX plant construction and that the "wide-ranging technically competent" report should be issued. Regarding prevention/mitigation of red oil caused explosions in closed systems, the ACRS offered that the applicant's technical bases are not clear for its claims that sufficiently large vents and provision for quenching can be used to control temperatures below 125 °C to prevent runaway reactions resulting in closed systems explosions.

DPO Submittal (January 14, 2005) -- Although the safety evaluation of the CAR concluded that 10 CFR 70.23(b) requirements were satisfied, i.e. the design basis of the PSSCs and the quality assurance program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents; your DPO dated January 14, 2005, disagreed with the safety evaluation conclusions concerning prevention/mitigation of red oil explosions in MOX plant closed systems. Your differing view was that the MOX CAR did not provide sufficient information for red oil caused explosion prevention/mitigation design bases to satisfy the requirements of 10 CFR 70.23(b). In your DPO and in a memo dated June 15, 2005, your concerns were further explained with supporting rationale, and you requested the following remedies to resolve the DPO: (1) the NRC management/staff decision to accept the applicant's strategy for closed systems be reversed; (2) Issue CS-01 on red oil reactions for the MOX application be reopened; and (3) for the construction application, the applicant be requested to submit on the docket adequate justification for its safety approach for red oil in closed systems and provide adequate justification for differences with the safety strategy used in DOE facilities and accepted by DOE/Defense Nuclear Facilities Safety Board (DNFSB) or alternatively apply a construction permit condition that imposes the DOE/DNFSB safety strategy until the applicant justifies its approach. By memo dated June 15, 2005, you provided additional proposed remedies, i.e., (1) communicate the safety concerns to the applicant as soon as possible; (2) impose the Routinely Accepted or Generally Accepted Good Engineering Practices (RAGAGEP) on the applicant; (3) inspect the applicant's test program and results on a routine basis; and (4) inspect red oil strategy evolution during detailed design and construction.

DPO Panel Report (February 21, 2007) -- In accordance with NRC Management Directive (MD) 10.159, "The Differing Professional Opinions Program," dated May 16, 2004, and by memorandum dated March 2, 2005; the Director of the Office of Nuclear Material Safety and Safeguards (NMSS) appointed a panel to review the subject DPO. The panel met with you on April 18, May 2, and May 5, 2005, to discuss and ensure its understanding of the DPO. In a June 15, 2005, memo, you provided the panel with additional information and remedies for DPO resolution. The panel documented its understanding of the DPO in an August 5, 2005, memo provided to you (Enclosure 2), and the panel did not receive contradictions to its understanding of the DPO. The panel also met with NRC MOX project managers and a management representative from FCSS (the NRC division responsible for CAR review). The panel considered MOX-related documentation from you, the MOX applicant, the Division of FCSS, the ACRS, the Center for Nuclear Waste Regulatory Analysis (CNWRA), and the Commission. The aforementioned meetings and documentation provided information for the panel to begin its review of the DPO. During its review of the DPO, the panel also utilized subject matter expert technical assistance from the NRC's contractor, the CNWRA.

The panel did not find sufficient basis in the DPO to recommend reversing the staff's decision to issue the construction authorization. The NRC construction authorization, based on review of the applicant's submittal, was intended to preclude the need for substantial plant backfitting to obtain a future NRC license. The MOX plant applicant relied on a different approach than DOE – with additional research – to preclude red oil events. The panel report stated that you objected to this approach. The applicant, by relying on future research, accepted the risk that the staff could find their approach unacceptable. Further, the contractor for the panel did not identify significant costs associated with any potential backfit.

The parties involved in reviewing the red oil issue at the proposed MOX facility generally agree that there was insufficient safety and technical information supplied in the CAR for a license application review. Although the specific technical questions differed; you, FCSS, the ACRS, the CNWRA, and the panel all concluded that significant technical questions remain unanswered. The technical questions were highlighted in the CNWRA's October 2006 assessment of red oil runaway reactions potentially causing explosions in the MOX plant aqueous polishing process units.

The panel recommended that: (1) the construction authorization for the MOX plant should not be revisited; (2) the staff should review the panel's report, particularly the attached CNWRA's report, for technical issues during the license application review of the MOX plant; (3) the staff should ensure that technical insights gained from the CNWRA's report are factored into the inspection program, as appropriate; and (4) the staff should review the CNWRA's hazard analysis for possible application during the license application review. The panel also found merit in your safety concerns (i.e., a MOX plant red oil explosion could have high consequences), but understood that the NRC staff, ACRS, and panel all recognize that these concerns need to be addressed by the applicant through the results of their research, the integrated safety analysis (ISA) results, or modifications/backfitting as appropriate. The panel concluded that the technical issues associated with the DPO need to be resolved at the license application review stage and that questions need to be dispositioned during that stage of the review.

<u>DPO Decision (March 23, 2007)</u>

The NMSS Director agreed with and adopted the panel's responses and recommendations, subject to the following clarification and direction:

- The construction authorization for the MOX plant does not need to be revisited. The staff recognized, in preparing the SER, that the applicant would need to provide additional information at the time of the licensing review regarding its approach to controlling red oil events, and the applicant committed to provide such information.

- The technical issues can and should be evaluated as part of the licensing review. As part of the license review process, it is the applicant's responsibility to demonstrate to the staff adequate protection of public health and safety and the environment with respect to preventing or mitigating red oil runaway reactions. To that end, the Director, NMSS, directed the staff to: (1) review the DPO panel report and contractor's report for technical issues that should be evaluated as part of the licensing process and request the applicant provide its safety bases to support the staff's evaluation of those issues; (2) document the disposition of the technical issues in the SER supporting the licensing decision; and (3) ensure that the inspection program for construction and operation provides verification of the design and operating features identified by the applicant and documented in the staff's SER as necessary to prevent or mitigate red oil runaway reactions.

- The Director, NMSS, also directed the staff to make use of the contractor's assessment of the relative risks of different parts of the MOX process to help risk inform the license application review and documentation process and the construction and operation inspection programs.

The Director, NMSS, thanked you for participating in the DPO process and stated that an open and thorough debate about how we carry out our regulatory programs is essential to keeping these programs effective.

DPO Appeal Submittal (April 18, 2007) -- Your DPO appeal noted that the applicant proposed strategies for controlling potential red oil events in open and closed systems and that you believed the applicant had not followed the accepted DOE practice nor provided a clear rationale or calculational basis for their control strategies. It stated that the strategy for open systems does incorporate some aspects from the accepted practice at DOE facilities that limit reaction temperatures and organic compounds and provide for vent sizes that have adequate margin within the recommended safe range identified by DOE and the DNFSB. However, it also stated that you believed that, for closed systems, the applicant's approach focuses primarily on the control of a single parameter – temperature and that the temperature design basis is higher than the effective temperature in open systems. By comparison to the accepted practice at DOE facilities, the appeal stated that you believed that the temperature design basis and vent sizing for closed systems are well into the unsafe range.

The DPO appeal stated that the main reasons for submitting an appeal were as follows: (1) the final decision and the DPO panel report have an underlying theme of inaction even though the DPO panel report validates the technical safety concerns of the DPO and states there is unanimity between the DPO, ACRS, CNWRA, and FCSS staff that significant technical issues remain (this oxymoron contradiction requires explanation); (2) FCSS and/or NMSS prejudicially commented against the DPO during the review, thus creating a bias; (3) the information in and attached to the DPO panel report indicates an unresolved safety question exists; and (4) other reasons submitted in the April 18, 2007, letter.

The April 18, 2007, DPO appeal stated that none of your previous comments had been addressed, that your main concerns remained, and that you believed the management system inappropriately commented on the DPO and its safety concerns during the DPO review, thus creating a prejudicial bias against the DPO. Your April 18, 2007, DPO appeal restated and elaborated on the dissenting views in your March 12, 2007, comments on the DPO panel report with inclusion of the Office Director's decision and the DPO Panel Chairman's cover letter, listed several demands, and stated several observations.

- Your DPO appeal stated that the Office Director's decision, the DPO Panel Chairman's cover letter, and the DPO panel report represent an outrageous farce and that the recommendations of inaction do not comport with the findings and conclusions in the report which, in short, agree with the safety concerns raised by the DPO. Your appeal stated that phrases like "significant unanswered technical questions," "unclear technical bases," "it is unclear how the design bases will provide adequate protection," and "high consequences" are not phrases that seem compatible with NRC regulations and acceptance even at the construction stage. Your appeal also stated that unanimity between you, the FCSS staff, the ACRS, the CNWRA, and the DPO panel that significant technical questions remain unanswered is extremely significant. In addition, your appeal stated that inaction or limited action on identified safety concerns is neither in alignment with the 10 CFR Part 70 regulations nor with the NRC Strategic Plan goals of ensuring safety, openness, effectiveness, and management excellence.

- Your appeal stated that you demanded that: (1) the DPO panel report recommendations of inaction/limited action are corrected to reflect proactive steps to resolve the safety concerns of the DPO and the DPO panel report findings and conclusions that might include reopening the safety issue, making it an action item, and adding it to a tracking system; (2) the contractor report be made fully publicly available because it is very critical of the applicant's approach and because its non-public categorization gives the appearance of a cover-up; (3) the letter from FCSS management to NMSS prejudicially commenting against the DPO and the safety issues (circa late 2005) and any other letters, emails, communications, or interactions between NMSS and FCSS management and the DPO panel are made fully publicly available; and (4) the DPO panel report acknowledge the fact that the DPO was submitted by the lead chemical safety reviewer for MOX, who has now been redirected by management to work on non-MOX activities.

- Your appeal also noted that the letter from FCSS management to NMSS which prejudicially commented against the DPO and the safety issues (circa late 2005) and the associated communications violate the scope given to the DPO panel by the Director, NMSS.

- Your appeal noted that there appeared to be an evolution in the FCSS conclusions on the red oil issue. In the Final SER (FSER) (NUREG-1821), pages 8-51, it states in part, "... the staff concludes the applicant provided sufficient defense-in-depth provisions ...[;]" "... the applicant provided sufficient controls and margin ...[;]" and the "applicant's proposed aqueous injection system extends beyond the safety requirements at DOE facilities and the operating French MOX facility." Yet, based upon the aforementioned unanimity found by the DPO panel, the FCSS staff now has significant unanswered technical questions. This was noted as a significant change.

- Your appeal noted that there have been changes in the applicant's safety strategy. A settler/decanter has been added as safety equipment. However, the applicant previously informed the NRC that this equipment would fail at least annually based upon French and other industry experience. In addition, the CNWRA contractor report identified the inadvertent transfer of organic materials to concentrated nitric acid solutions as an expected event. Thus, there is no improvement in safety. There is no additional information provided in the license application and ISA summary to support the effectiveness of the red oil safety strategy. Commitments are not mentioned in the construction permit or the revised license application, thus raising questions about commitment effectiveness and the nexus to NRC enforcement.

- Your appeal noted that a review of a recent report by Brookhaven National Laboratory ("Risk Assessment of Red Oil Excursions in the MOX Facility," BNL-MOX-2007-001) indicates the proposed safety strategies are not likely to meet the highly unlikely criterion for high consequence events. This report did not review the adequacy of the design bases and PSSCs to address the red oil hazard (it assumed they were correct); it only analyzed likelihoods.

- Your appeal also noted that the DPO panel report implies a concern regarding the 10 CFR Part 70 regulations and stated that the DPO panel report seems to be hinting there is an issue with the regulation, 10 CFR 70.23(b), and SECY-188 (the original Statement of Considerations). If this is the case (for example, 70.23(b) uses 'may' instead of 'shall' in its last sentence), then the appeal stated that you believed it should be highlighted by the DPO panel report and that a recommendation be made to correct the regulation (e.g., by a rulemaking) as other 10 CFR Part 70 applications are possible or even likely in the near future.

- Additionally, the appeal stated that you believed that the DPO panel and CNWRA contractor reports raise many questions about the applicant's proposed safety strategy for red oil including safety margins, reliabilities, event scenarios, etc. Therefore, the appeal stated that you believed that an unresolved safety question likely exists and needs a schedule with timely resolution.

- Finally, your appeal expressed concern that you have been directed by management to primarily work on other programs and issues rather than on MOX and that this reassignment gives the appearance of retaliation for raising safety issues on MOX and writing DPOs.

Office Director Views on DPO Decision and Contested Issues (July 27, 2007) -- The new Director, NMSS, reviewed the March 23, 2007, DPO decision by the former NMSS Director; met with the DPO panel on July 12, 2007; met with you on July 19, 2007; and did not identify substantially new information that would warrant revision to the former NMSS Director's decision on this DPO.

Executive Director for Operations Review and Decision -- When I received your appeal, I initiated an extensive review of the available information related to DPO-2005-002. I reviewed many documents including, but not limited to, your January 14, 2005, DPO submittal; the February 21, 2007, DPO panel report and it's enclosures; the CNWRA October 2006 report, "Assessment of Red Oil Runaway Reactions Potentially Causing Explosions in the MOX Aqueous Polishing Process Units;" the Office Director's March 11, 2007, comments on the DPO panel report; your March 12, 2007, comments on DPO panel report; the March 23, 2007, DPO decision; your April 18, 2007, DPO appeal submittal; and the Office Director's July 27, 2007, views on both the DPO decision and your contested issues. In order to fully understand the issues, I also met with members of the DPO panel on October 15, 2007, and offered to meet with you. Additionally, I acknowledge receipt of your October 15, 2007, memorandum stating your views that I had the information necessary to make a decision regarding your DPO appeal and that there was no reason for us to conduct a separate meeting.

I would like to commend you on a package that was well researched and insightful. I understand that you served as the lead chemical safety reviewer during the review of the CAR for the proposed MOX facility and that your principal concern is that NRC has not been sufficiently proactive in reviewing this issue and ensuring that the applicant is implementing appropriate controls to resolve the issue. However, based on all of the available information, I support the conclusions made by the panel in the final panel report as well as the Office Director's views on both the DPO decision and your contested issues. The basis for my decision is as follows:

Existing Regulatory Framework and Two-Step Licensing Processes -- The requirements of 10 CFR Part 70 involve a two-step process (an NRC authorization to construct the plant and then, prior to possessing nuclear material, an NRC license). For plant construction authorization, the NRC requires an acceptable design bases for the PSSCs relied on to control natural phenomena and accident caused risks in accordance with 10 CFR 70.61 performance requirements. In accordance with 10 CFR 70.23(b), construction of the PSSCs of a plutonium processing and fuel fabrication facility will be approved when the Commission determines that the design of the PSSCs and the quality assurance program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents. The PSSCs are based on a preliminary design bases, rather than on an ISA of the final design, which must be completed and included as part of the docketed license application. The underlying purpose of the NRC construction authorization is to assure that adequate preliminary consideration has been given to natural phenomena hazards and postulated accidents at the proposed plant so that subsequent substantial backfits will not be necessary to satisfy NRC's 10 CFR Part 70 licensing requirements for possession and use of nuclear material, e.g., SNM.

- The MOX fuel fabrication facility is being designed and constructed to process plutonium from nuclear weapons into fuel for commercial nuclear power reactors to generate electricity and is, therefore, subject to the requirements of 10 CFR Part 70, which involves a two-step licensing process (an NRC authorization to construct the plant and then, prior to possessing nuclear material, an NRC license).

- As noted in your July 19, 2007, NMSS Office Director, discussion slides; the ACRS recommended issuing a construction permit and FSER but identified issues that should be followed and stated that applicant's technical basis for the red oil conclusions were not clear.

- The construction permit was subsequently granted because sufficient information was provided to determine that the design of the PSSCs and the quality assurance program provided reasonable assurance of protection against natural phenomena and the consequences of potential accidents. As previously stated, the PSSCs are based on a preliminary design bases, rather than on an ISA of the final design, which must be completed and included as part of the docketed license application.

- Since there was agreement on the safety significance of red oil events and the importance of ensuring that proper safety controls, both engineered and administrative, are effective in preventing such events (as noted in the NMSS Office Director's July 27, 2007, views); the root of the differing views is related to the current regulatory framework of the existing construction and license applications review (two-step) processes and the type of information required for acceptance during the CAR phase versus the license application review phase. I believe that the staff followed the current regulatory process and that the technical issues associated with your DPO and the CNWRA's questions will have to be resolved before the license application is approved.

Status -- The staff's review of the applicant's assessments and controls to prevent red oil events is currently ongoing as part of the broader chemical safety review in accordance with the requirements in 10 CFR Part 70. The DPO panel report and contractor's analysis will be utilized to aid the staff in considering the safety of systems prior to issuance of the operating license, and a ticket to track the resolution of the red oil issue will also be generated by NMSS.

Unreviewed Safety Question (USQ) -- Your appeal stated that the information in and attached to the DPO panel report indicates that a USQ exists. The potential USQ will be considered during an ISA of the final design, which must be completed and included as part of the docketed license application prior to license approval. I would also like to note that this issue is not a generic issue because the MOX facility is currently unique in the United States.

Public Availability of Documentation -- I understand your concern regarding the need to make the documents associated with your DPO publicly available. Now that the DPO process is complete, the DPO records will be handled in accordance with the guidance in MD 10.159. In particular, those records that I have deemed to be essential to an understanding of the case (including the CNWRA report) will be made publicly available after they have been subjected to a reasonability review consistent with the agency's policies and practices.

Conclusion – While I agree with your DPO safety concerns; i.e., a MOX plant red oil explosion could have high consequences, I also agree with the DPO panel's conclusions that the NRC staff, ACRS, and panel all recognize that these concerns need to be addressed by the applicant through the results of their research, the ISA results, or modifications/backfitting as appropriate and that the technical issues associated with your DPO and the CNWRA's questions need to be resolved at the license application review stage.

I want to thank you again for raising your concerns to my attention. Your perseverance in raising these concerns demonstrates your dedication and passion to public health and safety. Your willingness to use the DPO Program has identified issues that will aid the agency prior to granting an operating license. Although you did not take the opportunity to meet with me to address your DPO appeal, I hope that you appreciate that I have thoroughly considered your views in making my decision.

In accordance with MD 10.159, a summary of this DPO appeal decision will be included in the Weekly Information Report posted on the NRC's public web site to advise interested employees and members of the public of the outcome.

Enclosures:
1. MOX Plant Design Bases to Prevent/ Mitigate Red Oil Explosion Consequences
2. August 5, 2005, Memorandum Documenting the DPO Panel's Understanding of the DPO

MOX Plant Design Bases to Prevent/Mitigate Red Oil Explosion Consequences

The proposed mixed-oxide (MOX) fuel fabrication facility plant utilizes a solvent extraction process with two immiscible liquid phases, an aqueous phase (nitric acid) and an organic phase (tri-*n*-butyl phosphate or TBP) to separate out plutonium. Above certain temperatures, when the two phases are in contact, red oil can be formed. The organic phase can degrade over time. However, at elevated temperatures, it can degrade rapidly, producing compounds that change the color of the organic phase from amber to dark red–hence the name "red oil." When heated, the red oil formation is exothermic, and can become autocatalytic, and if the vessel is not sufficiently vented or the temperature is not sufficiently controlled, an explosion can occur. An explosion could permit uranium and plutonium to escape the process and building containing the process. The red oil caused explosion could have high consequences for worker and public safety, as well as the environment.

In the construction authorization request (CAR), the MOX applicant proposes a red oil consequence prevention/mitigation strategy that differs from practices recommended by the U.S. Department of Energy/Defense Nuclear Facilities Safety Board. Rather than providing vents of sufficient size in certain parts of the process to preclude a red oil explosion, the applicant proposes the following for closed systems: (1) evaporative cooling rate safety margins; (2) temperature limits; (3) residence time limits for organic compounds in the presence of oxidizers and radiation fields; (4) aqueous phase addition in the event of temperature excursions; and (5) use of organic diluents which are resistant to red oil phenomena. As noted in the staff's Final Safety Evaluation Report, Duke, Cogema, Stone, and Webster commits in the CAR to perform research to confirm the effectiveness of the proposed strategy's prevention and mitigation of red oil consequences. The research also will evaluate the effect of impurities on the red oil phenomena initiation temperature. The MOX plant CAR describes the mix of features to avoid over-pressurization and thereby reduce the risk of red oil explosion caused consequences in closed systems: An off-gas system is intended to vent vessels/equipment that may potentially contain TBP and associated byproducts in nitric acid. A design basis steam temperature and a maximum heating rate are intended to limit the heat generation rate. Further risk reduction is achieved by means of a maximum design basis bulk fluid temperature, a diluent used as a chemical safety control, and a non-safety diluent washing system to preclude the transfer of organics to heated equipment. In addition, an aqueous injection system is intended to mitigate potential red oil reactions if the temperature should exceed a design basis temperature.

August 5, 2005, Memorandum Documenting the DPO Panel's Understanding of the DPO

NOTE: This document (ML070520310) was also used as Attachment 2 to the February 21, 2007, DPO panel report.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

August 5, 2005

MEMORANDUM TO: Alex P. Murray, Sr. Chemical Engineer
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Material Safety and Safeguards

FROM: Ad Hoc Review Panel[1] - DPO 2005-002 William H. Ruland/for

SUBJECT: PANEL'S UNDERSTANDING OF YOUR DPO ISSUES REGARDING RED OIL EVENTS AT THE PROPOSED MIXED OXIDE (MOX) FUEL FABRICATION FACILITY

This memorandum provides you our current understanding of your issues, based on: (1) our reading of the Differing Professional Opinion (DPO) you submitted on January 19, 2005; (2) our meetings with you on April 18 and May 2, 2005; and (3) our review of other documents related to the Red Oil issue. We are sending you this memorandum in accordance with the March 2, 2005, memorandum from Jack Strosnider to the Panel, where he established the panel and tasked us to document the panel's understanding of your issues with a copy to him.

Your DPO was made during the Construction Authorization review stage, not at the license application review stage. Thus, the panel infers that you concluded that Duke Cogema Stone & Webster (DCS) has not met the criteria that, as stated in 10 CFR 70.24(b), "...the *design bases*[2] of the *principal* structures, systems, and components, and the quality assurance program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents." (emphasis added)

Using your ten concerns listed in your DPO and repeated here for clarity, we understand your concerns as follows:

1. *Your statement* - Contradictions with DOE/DNFSB RAGAGEP are not explained. In particular, the RAGAGEP shows the applicant's proposal for closed systems being entirely in the unsafe regime (Figure2).

   Panel understanding - The applicant, DCS, did not provide any calculations or other technical basis why DCS was not designing their system to meet the Department of Energy (DOE)/Defense Nuclear Facility Safety Board (DNFSB) criteria for system design. You described that criteria as RAGAGEP, or Routinely Accepted or Generally Accepted Good Engineering Practices. While DCS meets some of the criteria, they do not meet all DOE design practices and, in particular, they have not designed all their affected systems to avoid the "unsafe region" described in Paddleford and Fauske, "Safe Venting of 'Red Oil' Runaway Reactions."

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[1]William H. Ruland, Chairman; Walter S. Schwink and A. James Davis, Ph.D, members

[2]Design Bases as defined in 10 CFR 50.2.

2. *Your statement* - There is inadequate margin in the design basis temperature.

Panel understanding - DCS has provided inadequate margin in the design basis temperature for the MOX process. You stated that DOE uses 120°C as the temperature limit, yet DCS is using 125°C for closed systems. Your concern centers around your statement that, at 125°C, the increase in enthalpy in the process liquid is 80% due to heat generated by the chemical reactants, instead of where it normally gets the bulk of its increase in enthalpy, the heating steam. Thus, you believe that setting the limit at 125°C permits operation at a point that already compromises safety.

3. *Your statement* - The venting is insufficient to avoid choked flow and pressurization, which has the ability to rapidly raise the temperature even with the applicant's proposed strategy functioning.

Panel understanding - DCS has provided insufficient information on the docket for you to determine if the vents provided in the system would preclude choked flow upon increased temperature, and thus you had insufficient information to determine whether or not the vents were sized properly to prevent a red oil reaction.

4. *Your statement* - Controls on organic compounds are inadequate - the applicant has indicated organic carryover is an anticipated event.

Panel understanding - DCS provided no controls on organic compounds. Given their other controls, this is insufficient to ensure that red oil reactions will not occur.

5. *Your statement* - There are no controls on acid or solvent concentrations.

Panel understanding - DCS provided higher nitric acid or Tributylphospate concentrations in the process than warranted. This leads to increases in the hydrolysis reaction, which may contribute to the likelihood of a red oil reaction.

6. *Your statement* - The evaporators at the proposed facility have a high aspect ratio which is more favorable for red oil reactions to occur and potentially cause pressure excursions.

Panel understanding - DCS provided evaporators with an aspect ratio (height/diameter) of about 5 to 10, which is higher than the typical 1 to 2. This information on aspect ratio was not in the docketed submittal, so that, given the way DCS is controlling the other key parameters, no conclusion could be reached about whether or not this part of the design was satisfactory.

7. *Your statement* - The NRC management decision accepting the applicant's proposal is based upon a voting process that included unqualified reviewers. It is not a consensus process.

Panel understanding - The NRC management decision process used to accept the DCS proposal to control red oil reactions was improper. Management held a vote to determine the acceptability of the DCS proposal but only two qualified reviewers participated in the vote. The implication here is that only technical reviewers are qualified to make this type of decision.

8. *Your statement* - Efficiency arguments were used by management as part of the rationale for accepting the applicant's proposal. However, efficiency is not mentioned in the regulations or as part of the SRP acceptance criteria.

Panel understanding - NRC management used process efficiency arguments as part of the rationale to accept the DCS proposal on limiting red oil events. Namely, by selecting the values of parameters for control at the values proposed, DCS will generate less waste but this is not an acceptance criterion in the Standard Review Plan.

9. *Your statement* - A significant portion of the management decision relies upon future commitments, efforts, and experiments to define/refine current PSSCs and design bases that are not RAGAGEP.

Panel understanding - The NRC management decision to accept the DCS red oil control strategy incorrectly relied on *future* commitments for research or actions to refine or define the *current* Primary Structures, Systems, and Components (PSSC) and design basis. In your words, "technically, we have approved the plant." That is, you believe that the NRC has inappropriately created the bounds for the plant, and you question whether or not the NRC has a clear basis for accepting the design.

10. *Your statement* - Overall, safety concerns from the NRC staff's Revised Draft Safety Evaluation Report (RDSER) are not addressed, including inconsistencies with other limits and a clear logical or calculational basis from the applicant indicating their integrated control strategy has the ability to meet the regulations. The applicant has made an assertion - supporting information from the applicant and the prevailing staff opinion is no-existent or inadequate to support a conclusion of adequate assurances of safety.

Panel understanding - Your concluding issue is that the NRC staff did not correctly disposition the safety issues in the Revised Draft Safety Evaluation Report (RDSER). Due to a possible 40 kg contained in some vessels, the projected dose due to a red oil explosion could be as high as 80 Rem TEDE with > 25 Rem at the site boundary. This information, in your opinion, argues for a detailed review at the construction authorization stage, unlike the inadequate or non-existing analysis from the license.

Also, you requested three remedies in your original DPO submitted in January 2005. As part of our interview with you on May 2, 2005, we asked if your proposed remedies had changed, since the Construction Authorization had now been issued. By memo dated June 15, 2005, (attached) you restated some of your original concerns; supplied us with additional comments, including your views on the March 23, 2005, Strosnider to Reyes memorandum "Notification of NMSS Licensing Actions"; restated your original proposed remedies; and suggested that, "Perhaps a compliance plan and schedule could be established to address the safety issue."

Also in your June 15th, 2005, memo to the DPO Panel, you have offered some additional potential remedies as part of your proposed compliance plan:

(1) Communicate these risk significant safety concerns about functionality and operability of the red oil controls to the applicant as soon as possible;

(2) Impose the DOE/DNFSB RAGAGEP as a permit condition or amendment until the applicant demonstrates that their proposed safety control strategy can actually perform its intended safety functions;

(3) Inspect test program and results on a routine basis; and

(4) Inspect red oil control strategy evolution (i.e., from system to component basis) during detailed design and construction.

As you have stated in your memo, your basic proposed remedies have not changed. Rather, you are seeking additional remedies in the form of communication with the applicant about the issue (No. 1 above), the imposition of a permit condition (No. 2 above), and the addition of inspections as part of a "compliance plan" (Nos. 3 and 4 above).

Panel Conclusions on Proposed Additional Remedies

Remedy No. 1 - Communication about safety concerns will be a natural outgrowth of any panel decision, based on the merits of the issues brought before the panel. Therefore, no additional action is warranted on this proposed additional remedy.

Remedy No. 2 - This issue is already captured by concerns Nos. 1 and 9 in the original DPO. Therefore, no additional action is warranted.

Remedy Nos. 3 and 4 - Inspection is one possible way to address issues that come before a DPO panel. As contained in the memorandum that chartered the panel, we were asked to "Make recommendations to me (Mr. Strosnider) regarding the disposition of the issues presented in the DPO." The panel has discretion on whether or not to recommend inspections as part of the resolution to the DPO. We conclude that it would be premature to make a recommendation now. However, based on our ability to do so later, we conclude that no additional action is warranted on these proposed additional remedies at this stage in our review.

Thank you for providing us your concerns. We will contact you during our review with any additional questions that we may have. Please feel free to provide any additional clarification that you feel may be necessary on our understanding of your issues.

Attachment: As stated

cc: Jack Strosnider, NMSS
Renee Pedersen, OE
DPO Panel members

June 15th, 2005

To: Bill Ruland
Walt Schwink
Jim Smith

Subject: Further Thoughts on the Red Oil Differing Professional Opinion (DPO) and Remedies

First, thank-you for taking the time to discuss the red oil issue and the DPO with me.

Second, let me add a follow-on comment regarding the Part 70 regulations and the MOX SRP (NUREG-1718). Part 70 regulates special nuclear materials, and includes facilities like enrichment and fuel fabrication plants. As we discussed, Part 70 specifically requires NRC approval of the principal structures, systems, and components (PSSCs) of a plutonium processing and fuel fabrication plant. This approval requires a determination that the design bases of the PSSCs and the QA program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents (70.23(b)). The intent of the rule is multipurpose - educate staff and licensee, and address safety issues early, thus minimizing the potential for delays, expensive backfits, or facility abandonment. I am concerned that the letter and the spirit of the regulation have not been met for closed systems susceptible to the red oil phenomena - I cannot find a supporting basis for the determination of reasonable assurances of adequate safety, the available information contradicts the acceptability of the applicant's design bases, there is no support for adequate margin and conservatism, and I am concerned the NRC could be placed in the position of requiring costly backfits or exempting an as-built facility.

Third, some general statements on the issue. The applicant has identified the red oil event as a high consequence event with high safety significance (high consequence event is defined in the context of Part 70.61 - the performance requirements). There is unanimity between staff and management that the NRC agrees with the applicant that this is a high consequence event. The applicant has proposed controls (PSSCs and design bases) to prevent the event from occurring. No information has been supplied by the applicant to support the functionality and reliability of the proposed safety strategy (PSSCs and design bases) for closed red oil systems. The NRC FSER does not provide information to support the regulatory requirement for a determination regarding the proposed PSSCs and design bases for closed systems. There are multiple statements about future tests but these also neither address the regulatory requirement nor do they provide for adequate margin and conservatism - i.e., if the regulator is not sure about the applicant's proposal, why is it being accepted?

ATTACHMENT

Fourth, documents transmitting the MOX FSER package do not fully communicate the context of the safety reviews and include half-truths and errors. For example, the March 23, 2005 memorandum - "Notification of NMSS Licensing Action" - mentions the following:

- "The planned issuance of the CA [Construction Authorization] will occur before a related differing professional opinion (DPO) is resolved." This neglects to mention that there are three other DPVs/DPOs that the "system" is preventing from entering the DPO process.
- "An NMSS staff member filed DPO-2005-002 ..." - this is out of context: the "NMSS staff member" is actually the Lead Chemical Safety Reviewed assigned to MOX safety reviews by the Agency.
- "After specifically considering the red-oil hazard, the ACRS concluded that the FSER should be issued." This is only partially true. The ACRS issued a dichotomous letter some five pages long that recommended issuance of the FSER but also identified safety concerns, including hazardous chemical release, fire hazards, red oil, hydroxylamine nitrate, and waste handling. For the red-oil hazard, the ACRS specifically stated "The applicant's technical basis for these conclusions [prevent runaway red oil reactions] are not clear to us." Significantly, none of the ACRS safety concerns are mentioned in the "Notification" memorandum.
- "The NMSS staff consensus is that the MOX CA should be issued ..." No consensus process was used and the staff has actually had meetings to try and define "consensus."
- "The staff's consensus view is that DCS' proposed red-oil safety strategy is adequate." This is incorrect - there is no staff consensus among qualified chemical safety reviewers that the safety strategy is adequate - the memoranda are initiated and concurred upon by managers and program managers.
- "DCS has several design options [for the red-oil hazard] that require neither a significant redesign nor a retrofit of the facility." Such specific design option discussions did not occur with the applicant. As regards the organic phase decanter, the applicant specifically stated that it could not perform safety functions due to its poor reliability (i.e., an organic material carryover incident every one or two years).
- The memorandum does not mention the lack of discussion with the Lead Chemical Safety Reviewer regarding the safety issues. Obviously, how can an informed decision be made without listening to both sides of the safety issues?
- I also have concerns regarding the memorandum's statements on DPO appeals. The responses to the DPO appeals completely contradict the findings of the DPV panels, repeat the management position, and provide no regulatory clarity.

Fifth, I want to reiterate - it is erroneous to state the red oil safety conclusions (i.e., acceptance) presented in the FSER and its accompanying memoranda are the results of a consensus process. I, as the Lead Chemical Safety Reviewer, expressed concerns and would not accept the red oil strategies, PSSCS, and controls proposed by the applicant. Management brought in another chemical safety reviewer to support the management position of acceptance. The applicant changed their strategy several times; this addressed the concerns for the open system but I still had concerns with the closed system. The other chemical reviewer supported the management desire for acceptance and did not have concerns with the closed system. Thus, there is one reviewer against acceptance and one reviewer for acceptance. This is not consensus, no consensus process was used, and it is incorrect and misleading for the management letters to state consensus was used.

Sixth, the ACRS has reviewed the proposed MOX facility and CAR. The MOX management team requested ACRS to provide a simple (less than one page) letter. The ACRS provided a five page letter (i.e., long by ACRS standards) dated February 24, 2005. This endorsed the issuance of the FSER, construction, and proceeding with an integrated safety analysis. However, the ACRS letter raised several safety issues. For closed systems susceptible to the red oil phenomena, the letter states (page 4, second paragraph):

> "The applicant claims that sufficiently large vents and provision for quenching can be used to control temperatures below 125 C, which will prevent runaway reactions. The applicant's <u>technical bases</u> for these conclusions <u>are not clear to us."</u> (My emphasis added.)

The meeting transcripts also contain numerous questions and concerns the ACRS raised during staff presentations on MOX. Thus, it appears that the ACRS agrees with the DPO that an adequate basis (rationale) has not been provided for the applicant's proposed safety strategy. This raises the obvious question - why has the NRC accepted the applicant's safety strategy given these concerns which imply the regulatory requirement has not been met?

Finally, let me discuss potential remedies. The DPO requested the following in January 2005:

> (1) the NRC management/staff decision to accept the applicant's strategy for closed systems be reversed;
> (2) Issue CS-01 on red oil reactions for the MOX application be reopened;
> (3) for the construction application, the applicant is requested to submit on the docket adequate justification for its safety approach for red oil in closed systems and provide adequate justification for differences with the safety strategy used in DOE facilities and accepted by DNFSB/DOE (i.e., the RAGAGEP - reasonable and generally accepted good engineering practice); or, alternatively, the NRC should apply a construction permit condition that imposes the DOE/DNFSB safety strategy as the design basis until the applicant justifies its approach.

The ACRS letter was issued in February, while the FSER and construction authorization permit were issued in late March. NRC activities on MOX are at a low level due to delays in the DOE side of the program - significant activities may not resume until December 2005 or even sometime in 2006 - this delay was known when NRC issued the FSER and construction authorization. In light of this information and by comparison to construction permits for reactors, all three remedies proposed in the DPO still seem reasonable and valid. Perhaps a compliance plan and schedule could be established to address the safety issue.

I note that it is likely the prevailing opinion held by some members of management and staff is in alignment with my technical safety concerns and this should be acknowledged by the DPO report. Thus, as part of a compliance plan, it also seems prudent and reasonable during this program delay to:

- communicate these risk significant safety concerns about functionality and operability of the red oil controls to the applicant as soon as possible.
- impose the DOE/DNFSB RAGAGEP as a permit condition or amendment until the applicant demonstrates that their proposed safety control strategy can actually perform its intended safety functions.
- inspect test program and results on a routine basis.
- inspect red oil control strategy evolution (i.e., from system to component basis) during detailed design and construction.

Therefore, as part of a remedy, I would like to see a recommendation for a compliance plan and schedule, perhaps with the above items identified as possible milestones, in order to address the red oil issue in a timely manner.

Please contact me if you have any questions.

ATTACHMENT 2 to Panel Report

August 5, 2005 memo[5] documenting the DPO Panel's understanding of the DPO.

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[5]The August 5, 2005 memo documenting the DPO Panel's understanding of the DPO has one attachment, i.e., "ATTACHMENT 1, JUNE 15, 2005 MEMO RE: FURTHER THOUGHTS ON THE RED OIL DIFFERING PROFESSIONAL OPINION (DPO) AND REMEDIES," from the submitter.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

August 5, 2005

MEMORANDUM TO: Alex P. Murray, Sr. Chemical Engineer
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Material Safety and Safeguards

FROM: Ad Hoc Review Panel[1] - DPO 2005-002 *Walter S. Ruland/for*

SUBJECT: PANEL'S UNDERSTANDING OF YOUR DPO ISSUES REGARDING RED OIL EVENTS AT THE PROPOSED MIXED OXIDE (MOX) FUEL FABRICATION FACILITY

This memorandum provides you our current understanding of your issues, based on: (1) our reading of the Differing Professional Opinion (DPO) you submitted on January 19, 2005; (2) our meetings with you on April 18 and May 2, 2005; and (3) our review of other documents related to the Red Oil issue. We are sending you this memorandum in accordance with the March 2, 2005, memorandum from Jack Strosnider to the Panel, where he established the panel and tasked us to document the panel's understanding of your issues with a copy to him.

Your DPO was made during the Construction Authorization review stage, not at the license application review stage. Thus, the panel infers that you concluded that Duke Cogema Stone & Webster (DCS) has not met the criteria that, as stated in 10 CFR 70.24(b), "...the *design bases*[2] of the *principal* structures, systems, and components, and the quality assurance program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents." (emphasis added)

Using your ten concerns listed in your DPO and repeated here for clarity, we understand your concerns as follows:

1. *Your statement* - Contradictions with DOE/DNFSB RAGAGEP are not explained. In particular, the RAGAGEP shows the applicant's proposal for closed systems being entirely in the unsafe regime (Figure2).

   Panel understanding - The applicant, DCS, did not provide any calculations or other technical basis why DCS was not designing their system to meet the Department of Energy (DOE)/Defense Nuclear Facility Safety Board (DNFSB) criteria for system design. You described that criteria as RAGAGEP, or Routinely Accepted or Generally Accepted Good Engineering Practices. While DCS meets some of the criteria, they do not meet all DOE design practices and, in particular, they have not designed all their affected systems to avoid the "unsafe region" described in Paddleford and Fauske, "Safe Venting of 'Red Oil' Runaway Reactions."

[1]William H. Ruland, Chairman; Walter S. Schwink and A. James Davis, Ph.D, members

[2]Design Bases as defined in 10 CFR 50.2.

2. *Your statement* - There is inadequate margin in the design basis temperature.

   Panel understanding - DCS has provided inadequate margin in the design basis temperature for the MOX process. You stated that DOE uses 120°C as the temperature limit, yet DCS is using 125°C for closed systems. Your concern centers around your statement that, at 125°C, the increase in enthalpy in the process liquid is 80% due to heat generated by the chemical reactants, instead of where it normally gets the bulk of its increase in enthalpy, the heating steam. Thus, you believe that setting the limit at 125°C permits operation at a point that already compromises safety.

3. *Your statement* - The venting is insufficient to avoid choked flow and pressurization, which has the ability to rapidly raise the temperature even with the applicant's proposed strategy functioning.

   Panel understanding - DCS has provided insufficient information on the docket for you to determine if the vents provided in the system would preclude choked flow upon increased temperature, and thus you had insufficient information to determine whether or not the vents were sized properly to prevent a red oil reaction.

4. *Your statement* - Controls on organic compounds are inadequate - the applicant has indicated organic carryover is an anticipated event.

   Panel understanding - DCS provided no controls on organic compounds. Given their other controls, this is insufficient to ensure that red oil reactions will not occur.

5. *Your statement* - There are no controls on acid or solvent concentrations.

   Panel understanding - DCS provided higher nitric acid or Tributylphospate concentrations in the process than warranted. This leads to increases in the hydrolysis reaction, which may contribute to the likelihood of a red oil reaction.

6. *Your statement* - The evaporators at the proposed facility have a high aspect ratio which is more favorable for red oil reactions to occur and potentially cause pressure excursions.

   Panel understanding - DCS provided evaporators with an aspect ratio (height/diameter) of about 5 to 10, which is higher than the typical 1 to 2. This information on aspect ratio was not in the docketed submittal, so that, given the way DCS is controlling the other key parameters, no conclusion could be reached about whether or not this part of the design was satisfactory.

7. *Your statement* - The NRC management decision accepting the applicant's proposal is based upon a voting process that included unqualified reviewers. It is not a consensus process.

   Panel understanding - The NRC management decision process used to accept the DCS proposal to control red oil reactions was improper. Management held a vote to determine the acceptability of the DCS proposal but only two qualified reviewers participated in the vote. The implication here is that only technical reviewers are qualified to make this type of decision.

8. *Your statement* - Efficiency arguments were used by management as part of the rationale for accepting the applicant's proposal. However, efficiency is not mentioned in the regulations or as part of the SRP acceptance criteria.

   Panel understanding - NRC management used process efficiency arguments as part of the rationale to accept the DCS proposal on limiting red oil events. Namely, by selecting the values of parameters for control at the values proposed, DCS will generate less waste but this is not an acceptance criterion in the Standard Review Plan.

9. *Your statement* - A significant portion of the management decision relies upon future commitments, efforts, and experiments to define/refine current PSSCs and design bases that are not RAGAGEP.

   Panel understanding - The NRC management decision to accept the DCS red oil control strategy incorrectly relied on *future* commitments for research or actions to refine or define the *current* Primary Structures, Systems, and Components (PSSC) and design basis. In your words, "technically, we have approved the plant." That is, you believe that the NRC has inappropriately created the bounds for the plant, and you question whether or not the NRC has a clear basis for accepting the design.

10. *Your statement* - Overall, safety concerns from the NRC staff's Revised Draft Safety Evaluation Report (RDSER) are not addressed, including inconsistencies with other limits and a clear logical or calculational basis from the applicant indicating their integrated control strategy has the ability to meet the regulations. The applicant has made an assertion - supporting information from the applicant and the prevailing staff opinion is no-existent or inadequate to support a conclusion of adequate assurances of safety.

    Panel understanding - Your concluding issue is that the NRC staff did not correctly disposition the safety issues in the Revised Draft Safety Evaluation Report (RDSER). Due to a possible 40 kg contained in some vessels, the projected dose due to a red oil explosion could be as high as 80 Rem TEDE with > 25 Rem at the site boundary. This information, in your opinion, argues for a detailed review at the construction authorization stage, unlike the inadequate or non-existing analysis from the license.

Also, you requested three remedies in your original DPO submitted in January 2005. As part of our interview with you on May 2, 2005, we asked if your proposed remedies had changed, since the Construction Authorization had now been issued. By memo dated June 15, 2005, (attached) you restated some of your original concerns; supplied us with additional comments, including your views on the March 23, 2005, Strosnider to Reyes memorandum "Notification of NMSS Licensing Actions"; restated your original proposed remedies; and suggested that, "Perhaps a compliance plan and schedule could be established to address the safety issue."

Also in your June 15th, 2005, memo to the DPO Panel, you have offered some additional potential remedies as part of your proposed compliance plan:

(1) Communicate these risk significant safety concerns about functionality and operability of the red oil controls to the applicant as soon as possible;

(2) Impose the DOE/DNFSB RAGAGEP as a permit condition or amendment until the applicant demonstrates that their proposed safety control strategy can actually perform its intended safety functions;

(3) Inspect test program and results on a routine basis; and

(4) Inspect red oil control strategy evolution (i.e., from system to component basis) during detailed design and construction.

As you have stated in your memo, your basic proposed remedies have not changed. Rather, you are seeking additional remedies in the form of communication with the applicant about the issue (No. 1 above), the imposition of a permit condition (No. 2 above), and the addition of inspections as part of a "compliance plan" (Nos. 3 and 4 above).

Panel Conclusions on Proposed Additional Remedies

Remedy No. 1 - Communication about safety concerns will be a natural outgrowth of any panel decision, based on the merits of the issues brought before the panel. Therefore, no additional action is warranted on this proposed additional remedy.

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Thank you for providing us your concerns. We will contact you during our review with any additional questions that we may have. Please feel free to provide any additional clarification that you feel may be necessary on our understanding of your issues.

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cc: Jack Strosnider, NMSS
Renee Pedersen, OE
DPO Panel members

June 15th, 2005

To: Bill Ruland
Walt Schwink
Jim Smith

Subject: Further Thoughts on the Red Oil Differing Professional Opinion (DPO) and Remedies

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Second, let me add a follow-on comment regarding the Part 70 regulations and the MOX SRP (NUREG-1718). Part 70 regulates special nuclear materials, and includes facilities like enrichment and fuel fabrication plants. As we discussed, Part 70 specifically requires NRC approval of the principal structures, systems, and components (PSSCs) of a plutonium processing and fuel fabrication plant. This approval requires a determination that the design bases of the PSSCs and the QA program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents (70.23(b)). The intent of the rule is multipurpose - educate staff and licensee, and address safety issues early, thus minimizing the potential for delays, expensive backfits, or facility abandonment. I am concerned that the letter and the spirit of the regulation have not been met for closed systems susceptible to the red oil phenomena - I cannot find a supporting basis for the determination of reasonable assurances of adequate safety, the available information contradicts the acceptability of the applicant's design bases, there is no support for adequate margin and conservatism, and I am concerned the NRC could be placed in the position of requiring costly backfits or exempting an as-built facility.

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Finally, let me discuss potential remedies. The DPO requested the following in January 2005:

> (1) the NRC management/staff decision to accept the applicant's strategy for closed systems be reversed;
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The ACRS letter was issued in February, while the FSER and construction authorization permit were issued in late March. NRC activities on MOX are at a low level due to delays in the DOE side of the program - significant activities may not resume until December 2005 or even sometime in 2006 - this delay was known when NRC issued the FSER and construction authorization. In light of this information and by comparison to construction permits for reactors, all three remedies proposed in the DPO still seem reasonable and valid. Perhaps a compliance plan and schedule could be established to address the safety issue.

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Therefore, as part of a remedy, I would like to see a recommendation for a compliance plan and schedule, perhaps with the above items identified as possible milestones, in order to address the red oil issue in a timely manner.

Please contact me if you have any questions.

ATTACHMENT 3 to Panel Report

LIST OF PERSONS CONTACTED BY THE DPO PANEL

Alexander Murray,	Sr. Chemical Reviewer, NRC/FCSS
Andrew Persinko,	Former MOX Project Manager, NRC/FCSS
Bill Troskoski,	NRC/FCSS
Don Stout,	NRC/FCSS
Dave Brown,	Former MOX Project Manager, NRC/FCSS
Wes Patrick, Ph.D	Vice-President, CNWRA
Vijay Jain, Ph. D	Manager, Corrision Science & Process Engineering, CNWRA
R. Page Shirtum, PE	RPS Engineering
James Smith	NRC/FCSS
David Turner, Ph. D	Asst. Director, Non-Regulatory Programs, CNWRA
Asadul Chaudry, Ph. D	Manager, Mining, Geotechnical, and Facility Engineering, CNWRA

ATTACHMENT 5 to Panel Report

Center for Nuclear Waste Regulatory Analysis (CNWRA) Report
Assessment of red oil runaway reactions potentially causing explosions in the MOX aqueous polishing process units.

~~PREDECISIONAL~~
~~OFFICIAL USE ONLY~~

ASSESSMENT OF RED OIL RUNAWAY REACTIONS IN THE AQUEOUS POLISHING PROCESS UNITS OF THE MIXED OXIDE (MOX) FUEL FABRICATION FACILITY

Prepared for

U.S. Nuclear Regulatory Commission
Contract NRC–02–03–002

Prepared by

V. Jain
Center for Nuclear Waste Regulatory Analyses
R.P. Shirtum
Consultant

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

October 2006

~~PREDECISIONAL~~

ABSTRACT

On February 28, 2001, Duke Cogema Stone & Webster (DCS) submitted a request to the U.S. Nuclear Regulatory Commission (NRC) to construct a Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF) on the U.S. Department of Energy (DOE) Savannah River Site (SRS) near Aiken, South Carolina (DCS, 2001). In March 2005, NRC documented its review in the final safety evaluation report, and approved the DCS request for the construction of a MFFF (NRC, 2005). However, an NRC staff disagreed with the proposed DCS approach and the NRC staff evaluation pertaining to the potential for red oil events and filed a Differing Professional Opinion (DPO) (Strosnider, 2005). This report addresses concerns identified in the NRC DPO–2005–002 (Strosnider, 2005) pertaining to red oil runaway reaction in the Aqueous Polishing process units of the proposed MFFF. The Center for Nuclear Waste Regulatory Analyses assessment, based on review of the principal structures, systems and components (PSSC) and the preventive and mitigative solutions, indicates that red oil runaway reactions could be classified as not-unlikely high-consequence events for thermosiphon evaporators. The PSSC adopted by the DCS for preventing red oil runaway reactions for the closed thermosiphon evaporators may not be adequate. However, a review of some potential backfit options indicates that effective solutions can be obtained without an extensive retrofit and without significant construction cost implications.

References

DCS. "Mixed Oxide Fuel Fabrication Facility Construction Authorization Request." Docket 070-03098. Charlotte, North Carolina: DCS. 2001.

NRC. NUREG–1821, "Final Safety Evaluation Report on the Construction Authorization Request for Mixed Oxide Fuel Fabrication Facility at the Savannah River Site South Carolina." Washington, DC: NRC. 2005.

Strosnider, J.R. "Ad Hoc Review Panel—Differing Professional Opinion on Red Oil Events at the Proposed Mixed Oxide Fuel Fabrication Facility." Letter (March 2) to W. H. Ruland, NRC. DP–2005–002. Washington, DC: NRC. 2005.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: Relative hazard index determined in Appendix B was calculated using information provided in the Mixed Oxide Fuel Fabrication Facility Construction Authorization Request (Duke Cogema Stone & Webster, 2001 with change pages). The Microsoft® Excel Version 2002 SP3 program was used for calculations.

ANALYSES AND CODES: None.

Reference:

Duke Cogema Stone & Webster. "Mixed Oxide Fuel Fabrication Facility Construction Authorization Request." Docket 070-03098. Charlotte, North Carolina: Duke Cogema Stone & Webster. 2001.

1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

The licensing of the MOX Fuel Fabrication Facility (MFFF) under 10 CFR Part 70 is a two-step process. Authorization for construction is followed by the authorization to receive and possess special nuclear material. 10 CFR 70.23(b) provides requirements for construction authorization, which specifically requires the U.S. Nuclear Regulatory Commission (NRC) to conclude, prior to approving a construction authorization that the design bases of the principal structures, systems, and components (PSSC), and the quality assurance program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents. Furthermore, statements of consideration provided in the Office of Secretary (SECY) R–188 (NRC, 1971) indicate that the underlying purpose of construction authorization (first step of a two-step licensing process) is to ensure that adequate preliminary consideration has been given to natural phenomena hazards and postulated accidents at the proposed facility so that subsequent extensive retrofits will not be necessary to meet NRC requirements for possessing and using licensed materials (second step of the two-step licensing process).

On February 28, 2001, Duke Cogema Stone & Webster (DCS) submitted a request to NRC to construct a MFFF on the U.S. Department of Energy (DOE) Savannah River Site (SRS) near Aiken, South Carolina (DCS, 2001). In March 2005, NRC documented its review in the final safety evaluation report, and approved the DCS request for the construction of a MFFF (NRC, 2005). However, the Senior Chemical Process Engineer, who is also the lead Chemical Safety Reviewer for NRC, disagreed with the proposed DCS approach as well as the NRC staff evaluation pertaining to the potential for red oil events and filed a Differing Professional Opinion (DPO) (Strosnider, 2005). This DPO was assigned DPO–2005–002.

1.2 Objectives

In order to address concerns raised in DPO–2005–002, the key objectives of this report are to (i) assess the proposed classification of principal structures, systems and components (PSSC), (ii) assess the DCS design philosophy to mitigate or prevent red oil events in Aqueous Polishing process units, and (iii) evaluate backfit options that may be necessary to address concerns raised in DPO–2005–002.

2 BACKGROUND INFORMATION

2.1 Red Oil Runaway Reaction

Tributyl phosphate (TBP) is a widely used organic solvent in radioactive material reprocessing plants in the initial cycles of the Plutonium Extraction (PUREX) process to co-extract plutonium and uranium, leaving behind fission products such as cesium and technetium. TBP is mixed with diluents, which are C_{10}-C_{13} branched aliphatic hydrocarbons such as hydrogenated propylene tetramer (HPT) that are used as density control solvents (approximately 70 percent by weight). Red oil is defined as a mixture of C_{10}-C_{13} branched aliphatic hydrocarbons containing a complexation agent, TBP, and its complexes with plutonium or uranium, nitric acid, and degradation products of TBP (normally monobutyl and dibutyl phosphates, alcohols, and organic nitrates). Between 1953 and 1993, there were six documented red oil explosions

(Usachev and Markov, 2003). In the United States, two explosions occurred at the Savannah River Site, South Carolina; and one each at Hanford, Washington; and Oak Ridge, Tennessee. There also was one accident in Canada and one in Russia. Five out of six accidents took place in uranium reprocessing lines and one took place in a plutonium line. All accidents, except at Hanford, caused significant damage to structures and components. The evaporator at the Hanford reprocessing line was fitted with a rupture disk that provided rapid pressure equalization and minimized the effects of the explosion.

The rate of reaction between nitric acid and TBP is controlled by the TBP hydrolysis rate that produces dibutyl phosphate and n-butanol. The n-butanol can either volatilize at 117.5 °C [243.5 °F] or can be oxidized in the presence of nitric acid or nitrates. If oxidation occurs before volatilization, the heat of oxidation may exceed evaporative cooling causing an energetic runaway reaction and possibly an explosion in a confined space (Hyder, 1994a). In an open system, however, evaporative cooling assisted by removal of water vapor and gaseous reaction products limits the generation of heat and the buildup of pressure in the evaporators. Hyder (1994b) indicated that below 80 °C [176 °F] the self-heating is so slow that the natural processes provide adequate cooling. However, he cautioned that care is needed to ensure that adequate cooling is available at higher temperatures.

Paddleford and Fauske (1994) experimentally examined the role of venting in reducing the likelihood of a red oil accident. Samples were heated at a rate of 1–2 °C/min [1.8–3.6 °F/min] until self-heating was observed. In the vented system, boiling was observed around 115–125 °C [239–257 °F] with no self-heating until 130 °C [266 °F]. In the closed system, self-heating was observed at 116 °C [241 °F]. Using pure TBP saturated with 15 N nitric acid, Paddleford and Fauske (1994) showed that overpressurization initiates if the organic (TBP) mass-to-vent area ratio is greater than 310 g/mm^2 [7,055 oz/in^2].

Rudisill and Crooks (2001) examined the red oil runaway reaction temperature in a mixture containing one volume of TBP with five volumes of aqueous solution, and showed that the runaway reaction temperature decreases with increasing amounts of nitric acid. The lowest runaway reaction temperature in a 15 N nitric acid solution was 134 °C [273 °F] with an average initiating temperature of 137 °C [277 °F]. The decrease in the runaway reaction temperature was attributed to the increased extraction of nitric acid in the organic phase. Colvin (1956), which was referenced in Rudisill and Crooks (2001), indicated that red oil runaway reaction initiation could occur at a temperature as low as 129 °C [264 °F] in 9.6 M nitric acid solution. Rudisill and Crooks (2001), however, noted that the Colvin (1956) datapoint was an outlier.

In 2003, the Defense Nuclear Facilities Safety Board (DNFSB), partly based on the data by Rudisill and Crooks (2001), recommended that in addition to designing an adequate vent size, limits should be imposed on operating temperature and pressure, maximum organic mass, and maximum nitric acid concentration. A single control should not be used to prevent a runaway red oil reaction and explosion (Conway, 2003).

2.2 Summary of the DCS Approach

DCS has adopted a mix of preventive and mitigative safety strategies to avoid overpressurization in thermosiphon evaporators during a red oil runaway reaction event. [redacted]

(b)(2)High [redacted]

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- (b)(2)High
-
-
-

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DCS has established principal structures, systems, and components (PSSC) to implement a preventive safety strategy for thermosiphon evaporators, including

- Offgas treatment system
- Process safety control subsystem
- Chemical safety control

The safety function of the proposed offgas treatment system is to provide venting from vessels/equipment that may potentially contain TBP and associated byproducts in nitric acid solution. The design basis for the proposed vent size is consistent with the recommendation of Paddleford and Fauske (1994). (b)(2)High (b)(2)High (b)(2)High DCS has still credited the proposed offgas treatment system as PSSC for providing an exhaust path for âqueous phase evaporative cooling. The vent size is sufficient to remove (b)(2)High the heat input and heat generated by the exothermic self-sustained red oil reactions.

FOIA EX 2

DCS has proposed a design basis steam temperature of 133 °C [271 °F] and a maximum heating rate of 2 °C/min [3.6 °F/min] after startup to limit the heat generation rate. Furthermore, DCS has proposed 125 °C [257 °F] as the maximum design basis bulk fluid temperature. This ensures that diluents will not undergo degradation, and is below the lowest runaway reaction temperature. DCS stated that this finding is based on the experimentally determined minimum initiation temperature for a closed system; however, no reference was provided in the DCS Construction Authorization Request (CAR).

DCS has also identified the selection of a diluent, such as HPT, as a chemical safety control PSSC. In addition, DCS has proposed to implement the diluent washing by using either pulsed columns or mixer-settlers to preclude the transfer of bulk organic quantities to heated equipment. However, diluent washing systems were not credited as PSSC. In addition, DCS plans to include an Aqueous Injection system to mitigate potential red oil runaway reactions if the temperature exceeds design basis temperature.

2.3 Summary of the NRC Review

The NRC staff summarized their assessment on the red oil runaway reactions separately for open and closed thermosiphon evaporator systems in Section 8.1.2.5.5 of NRC (2005).

2.3.1 Open Thermosiphon Evaporator System

The NRC staff concluded that for the open (i.e., vented) thermosiphon evaporator system, the proposed organic (TBP) mass-to-vent area (b)(2)High is well below the organic (TBP) mass-to-vent area of 310 g/mm^2 [7,055 oz/in^2] above which red oil runaway reactions can

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be initiated (Paddleford and Fauske, 1994). Therefore, the NRC staff concluded that the vent size is large enough to maintain pressure at atmospheric levels.

2.3.2 Closed (Partially Vented) Thermosiphon Evaporator System

The NRC staff evaluated the design basis temperature for red oil runaway reactions and concluded that the average initiation temperature of 137 °C [279 °F] {range from 134–140 °C [273–284 °F]} for TBP in a 13.6 N nitric acid solution is appropriate. The NRC staff accepted that shutting down the steam and injection of aqueous phase material into the closed system evaporator is an adequate methodology to maintain bulk fluid temperature below 125 °C [257 °F]. (b)(2)High

(b)(2)High

For the closed thermosiphon evaporator system, the NRC staff concluded that DCS has provided sufficient defense-in-depth by proposing an approach that includes independent multiple temperature controls, an aqueous phase evaporative cooling (offgas treatment) system, and the exclusion of cyclic chain hydrocarbons. In addition, DCS committed in the amended license application to conducting additional research and development on the runaway initiation temperature and the effect of impurities on the initiation temperature, however, detailed plans were not provided for review.

2.4 DPO–2005–002 Summary

Based on the proposed approach by DCS in the MFFF CAR (DCS, 2001 with change pages) and the NRC review documented in Section 8.1.2.5.5 of NRC (2005), the following concerns related to the potential for red oil formation in thermosiphon evaporators were cited in DPO–2005–002 (Strosnider, 2005):

- The design basis maximum bulk fluid temperature of 125 °C [257 °F] has an inadequate safety margin.
- The DCS proposal for a closed system should be considered as entirely in the unsafe zone based on Reasonable and Generally Accepted Good Engineering Practice (RAGAGEP).
- In the closed system, venting is insufficient to avoid choked flow and pressurization.
- Controls on organic compounds are inadequate—the applicant has indicated organic carryover is an anticipated event.
- There are no controls on acid or solvent concentrations.

DPO–2005–002 (Strosnider, 2005) concerns are based on DCS not following the DNFSB (Conway, 2003) recommendations to implement multiple safety controls on multiple parameters such as temperature, pressure relief/vent size, total organic carbon, nitric acid concentration, and building confinement. In addition, DPO–2005–002 (Strosnider, 2005) states that DCS has not adopted DOE practices at the H-Canyon Facility located at the SRS for its control strategy (e.g., a limit of less than 10 N on nitric acid concentration, adequate vent size, and limiting the operating temperature) (NRC, 2005). For open systems, DPO–2005–002 (Strosnider, 2005) states that DCS has adopted some practices that provide a sufficient safety margin (e.g., vent size). However, for the closed (partially vented) system DCS has proposed a vent size that is in an unsafe regime (b)(2)High compared to the DOE H-Canyon Facility.

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3 ASSESSMENT OF RED OIL RUNAWAY REACTION IN AQUEOUS POLISHING PROCESS UNITS

In this chapter, the DPO–2005–002 issues are addressed by examining (i) the proposed classification of PSSC, (ii) the DCS design philosophy to mitigate or prevent red oil runaway reactions in Aqueous Polishing process units, and (iii) the backfit options that may be necessary to prevent red oil runaway reaction.

3.1 Classification of PSSC

Evaluation of PSSC in accordance with the Sections 5.4.3.1(E) and (F) of NUREG–1718 (NRC, 2000) requires consideration of the likelihood of occurrence of events and the associated consequences (i.e., radiation dose if events do occur). The mathematical product of the likelihood and consequence estimate provides an expected dose or dose risk.

Likelihood estimate. There have been six documented red oil accidents since 1953, indicating approximately one accident per decade (Usachev and Markov, 2003). If one assumes that there are 10 similar facilities worldwide, an approximate (because the number of data points is limited) likelihood of an accident can be estimated as 0.01 per facility per year [6 accidents /(10 facilities x 60 years)]. Based on this very gross estimate, it appears that the likelihood of such an accident during the lifetime of the proposed facility is not negligible. Consistent with this estimate, the DCS also categorized postulated explosive events as "not unlikely" (i.e., DCS did not exclude explosive events based on their low probability of occurrence). Although more than 10 facilities may have been operating during this period, which could lower the likelihood of postulated accidents, it is highly unlikely that the resulting probability estimate would reduce the categorization to Likelihood Category 2 (unlikely).

Consequence estimate. The CAR (Table 5.5-26) estimates a maximum mitigated dose to an individual outside the controlled (IOC) area located at 160 m [524.9 ft], as a result of a bounding explosion event, to be less than 0.003 Sv [300 mrem]. This estimate uses conservative assumptions with one potentially important exception: airborne particles are assumed to be filtered prior to release from the MFFF building. Taking credit for filtration tacitly (and perhaps unrealistically) assumes that the building would not be significantly damaged by a postulated explosion. The consequence calculations in the CAR for explosive events did not consider the potential failure of the roof of a building similar to what occurred as a result of the Tomsk-7 red oil event, where the explosion damaged the roof, thus providing a direct release path (Gilbert, et al., 1993).

DCS used a factor of 10,000 reduction in airborne particles based on a leak path factor (LPF) of 1×10^{-4} to mitigate explosion consequences. Assuming a linear relation between release and dose, the unmitigated dose (e.g., if the building is damaged such that filtration is completely ineffective) from an explosion event could be as great as 3,000 rem to an IOC located at 160 m

[524.9 ft] from the MFFF stack. This may classify explosions, based on consequences, as a high consequence event. Whether such a scenario is credible at the MFFF will require a more detailed examination of explosive power, structural design, and potential release pathways. Such information was not provided in the CAR.

Expected dose. The DCS calculation of expected dose (risk) is the same as described in the consequence calculation above, because the event is assumed to occur (i.e., the probability is 1.0). Using information currently available, the CNWRA estimates for the postulated case of a breach of the containment building, the expected value of the unmitigated dose is (30 Sv) × 0.01 = 0.3 Sv [(3,000 rem) x (0.01) = 30 rem] to the IOC. Based on this estimate, the postulated red oil runaway reaction would be classified as a high-consequence event. The above estimate, however, includes structural failure of containment. If the containment structure remained substantially intact following such an event, the risk would be further reduced.

Review of the MFFF CAR for structural systems indicates that DCS has committed to designing the Aqueous Polishing Cell structures to meet applicable codes and standards including designing for internal explosions. However, DCS has not committed to specific design parameters for applying the cited codes or standards.

3.2 Unit Operations

(b)(2)High [redacted]

(b)(2)High [redacted] Table A–1 of Appendix A shows the hazard index for various unit operations, relative likelihood of red oil runaway reactions in various components of each unit operation, and summarizes DCS proposed safety features that either mitigate or prevent red oil runaway reactions. The methodology for calculating relative hazard index is provided in Appendix B.

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(b)(2)High [redacted] the kinetics of a red oil runaway reaction are expected to be extremely slow because nitric acid concentration (less than 4.5 N) and temperature {below 60 °C [140 °F]} are both well below the reported threshold values for potential red oil runaway reaction conditions. Hyder (1994b) also indicated that below 80 °C [176 °F] the self-heating is so slow that the natural processes provide adequate cooling through adiabatic losses to prevent a thermal runaway. If a system was of a large enough scale, however, such that the surface area to volume of the equipment did not meet the assumptions of Hyder (1994b), a runaway reaction could occur. For example, large process tanks with little or no throughput flow, and the possibility of accumulating TBP degradation products might not be cooled sufficiently, allowing temperatures to rise over time.

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(b)(2)High [redacted]

FOIA EX 2

(b)(2)High [redacted]

FOIA EX 2

FOIA EX 2

Another possible scenario for a red oil runaway reaction includes a phase (density) inversion between the aqueous and organic phases. A phase inversion is postulated to occur at a point where the uranium complexed by the TBP in the organic phase results in an organic phase density that is greater than the surrounding acid (aqueous) phase density. In this scenario, the resultant trapped TBP phase would react and release heat by bubbling (boiling) through the overlying aqueous phase, reducing effective heat transfer and generating substantial surface area (mixing) between the acid and TBP phases in the interfacial region. (b)(2)High [redacted] (b)(2)High [redacted] (b)(2)High [redacted] At this degree of boil-up, a very turbulent and high velocity (high Reynold's number) flow condition would exist in the liquid path. The kinetics of chemical reactions, such as the hydrolysis of TBP, where there is limited solubility between reactants in immiscible phases (e.g., acid water and TBP), are often maximized when the interfacial reaction becomes dominant. This effect requires some level of shear rate intensity to generate the required surface area for mass transfer. To quantify the TBP kinetics for these potential scenarios, a calorimeter would need to be operated at the same shear rate as the thermosiphon reboiler, for example, using both phases present simultaneously.

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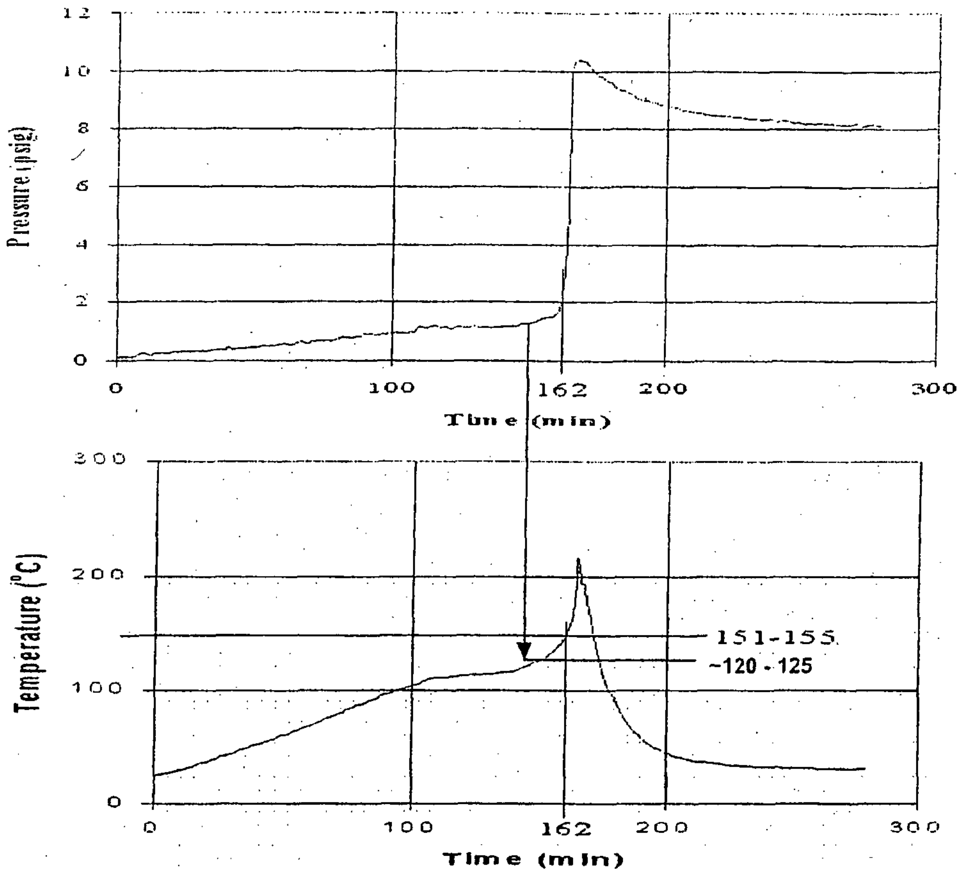
3.3 DCS Design Philosophy

The CNWRA staff examined the proposed DCS design philosophy to prevent or mitigate red oil runaway reactions in thermosiphon evaporators. While DCS has indicated that the MMMF is based on the similar facility in France, detailed information on the French facility is not available for review at this time. The assessment, based on Section 8.3(A)–(E) of NUREG–1718 (NRC, 2000), resulted in the following observations.

3.3.1 Design Basis Temperature

DCS has proposed using multiple independent temperature controls and monitoring equipment for temperature control in thermosiphon evaporators (NRC, 2005, p. 8-51). The proposed use of multiple independent temperature controls is adequate because it provides a good measure of temperature variability within evaporators.

Rudisill and Crooks (2001) examined the red oil runaway reaction temperature. The temperature of runaway reaction was based on the time at which the pressure spike occurred, as shown in Figure 3-1. A detailed examination of the Figure 3-1 indicates that the inflection in temperature (temperature versus time curve) could occur at a much lower temperature {approximately 30 °C [54 °F]} than the pressure spike temperature of 151 °C [304 °F].



Arrow indicates inflection point

Figure 3-1. Calorimetry Data Showing Temperature and Pressure Profile for a Typical Mixture of Tributyl Phosphate and Nitric Acid. The Arrow Shows the Inflection Point in Temperature Prior to the Pressure Spike at 162 Minutes (Rudisill and Crooks, 2001).

Additional tests may be needed to determine the minimum temperature for self-heating. The inflection point indicates a change in the heat generation rate due to self-heating. The temperature at which a pressure spike is observed is indicative of the progression of the red oil runaway reaction. The difference between the temperature at the inflection point and the temperature at which the pressure spike occurs depends on the physical properties of the reactor vessel (e.g., size and insulation). The difference may represent a delay in pressure buildup. If enough time is allowed, the pressure spike may occur at the inflection point. Therefore, the inflection point in the temperature profile where the temperature starts a sharp ascent may be considered as the upper limit beyond which controls would be ineffective, and throttling back to safe condition would be extremely difficult. Paddleford and Fauske (1994) observed the initiation of self-heating in a closed system at 116 °C [241 °F], which supports the observation by Rudisill and Crooks (2001) that the inflection point is the runaway reaction initiation temperature.

Furthermore, the temperature control setpoint of the evaporators under examination is very close to the observed self-heating temperature of the process fluids, assuming full excursions of chemical concentrations. Based on differential scanning calorimetry, the industrial and Materials Technologies Programme of the European Commission Project BET2–0572 (HarsNet, 2005) recommends the safety margin ($T_{onset} - T_{Process,\ maximum}$) as 100 °C [180 °F] for reactions with enthalpies above 80 kJ/mole [19.1 kcal/mole]. However, a general safe operating temperature margin for cases such as red oil runaway reaction usually starts with a design basis temperature which is 50 °C [90 °F] based on accelerating rate calorimetry data (HarsNet, 2005). The U.S. Chemical Safety and Hazard Investigation Board report on the October 13, 2002, First Chemical Corporation of Pascagoula, Mississippi, incident, concluded that a safety margin of between 20 and 42.2 °C [36 and 76.0 °F] for the design basis temperature of 210 °C [410 °F] proved to be inadequate in this case of organic nitrates. Also cited by the U.S. Chemical Safety and Hazard Investigation Board was an August 7, 1972, case at the Union Carbide Company facility in South Charleston, West Virginia, where another organic nitrate runaway reaction occurred. Previous experience with reactive chemicals testing at Union Carbide Company had indicated that the design margin of 42.2 °C [76.0 °F] for the design basis temperature of 232 °C [450 °F] was adequate. Neither of these cases prove that the red oil reaction would run away, but are used to illustrate that there is substantial uncertainty in determining a safety margin of temperature based on reactive chemicals testing (accelerated rate calorimetry).

Additionally, information presented by Conway (2003, p. 5-2) and NRC (2005, p. 8-43) implies that the steam temperature supplied to the steam chest of the evaporator is that of saturated steam at the regulated pressure. No details of the steam station design have been provided, though this assumption would generally be analyzed carefully in low safety temperature margin designs. If the temperature of the steam supply is not monitored and no desuperheater is employed, the steam can be hotter than the pressure dictates due to superheating. In such applications, steam temperature generally would be considered in a closed (partially vented) system thermosiphon evaporator design with a low temperature safety margin.

Moffat and Thompson (1961) examined the role of zirconium in TBP and nitric acid reactions and concluded that zirconium extracted into the organic phase from the aqueous phase greatly accelerates TBP decomposition. Hou, et al. (1996) did not observe red oil runaway reactions in the presence of zirconium; however, they attribute this to test conditions that were not appropriate for the study of red oil runaway reactions. DCS has not provided an assessment of the potential catalytic reactions that can initiate runaway red oil reactions at a lower temperature (DCS, 2001, with change pages). The NRC assessment in the safety evaluation report (NRC, 2005) indicates that DCS has, however, committed in the application as amended to conduct research and development to determine the effect of impurities.

The NRC staff review documented in Section 8.1.2.5.5 of NRC (2005) indicates a safety margin range of (b)(2)High [redacted] However, the difference between the design basis temperature {125 °C [257 °F]} and minimum temperature {134 °C [273 °F]}, based on the temperature at which a pressure spike occurs, is only 9 °C [16 °F]. Based on the foregoing discussion, the proposed safety margin is questionable. In addition, the NRC assessment indicates that the pressure increase required

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to raise the temperature by 4.6 °C [8.3 °F] is about 10 percent of the ambient offgas treatment system pressure (NRC, 2005). This analysis assumes there is no self-heating due to the initiation of red oil reactions and neglects generation of reaction products. Given only 9 °C [16 °F] safety margin in the design basis bulk fluid temperature, the occurrence of red oil reactions during normal operations and the frequent use of the aqueous injection system to suppress red oil runaway reactions cannot be ruled out.

Given that red oil runaway reaction could be classified as not-unlikely high-consequence event, the proposed safety margin for the design basis of the fluid bulk temperature of 125 °C [257 °F] is not supported by an adequate technical basis to ensure that chemical process safety controls can prevent or mitigate potential accidents.

3.3.2 Aqueous Injection System

The proposed aqueous injection system, which is a mitigative feature, is activated if the maximum fluid temperature exceeds the design basis temperature (NRC 2005, p. 8-51). The proposed aqueous injection system, which is a subsystem of the process safety control system, may not be adequate to provide relief on demand during a potential red oil event.

The Rudisill and Crooks (2001) data indicate that the pressure spike occurs perhaps within a minute. The response time of the process control system on demand to isolate steam and initiate aqueous injection may not be quick enough to counter a pressure buildup. Any automatically controlled valving for the purpose of blocking and isolating additional steam entry into the steam chest during a thermal excursion or other emergency triggering event generally would be actuated from an independent process variable monitoring device and accomplished with an independent block valve (not the main control valve), or more commonly a double block and bleed arrangement. Standard practice would classify this equipment as "critical to safety" and establish periodic testing and documentation to verify desired performance.

The Westinghouse Hanford Company (1994, p. 2-4) and Kudriavtsev (1994, p. 70) indicate problems with the use of valves in series with pressure relief equipment. This is reported to have possibly been a contributing factor in the Russian Tomsk-7 incident and warrants examination for the proposed design. Placing any manual or actuated valve in series with a safety relief device is unacceptable in the chemical processing industry. Furthermore, the aqueous ebulliently cooled design seems to rely on a pressure relief device to initiate the safe mode failure response. Safety relief valves are designed to relieve at a given pressure for a one-time response and a successful re-seating after relief. It is not standard industry practice or RAGAGEP to design an extended and dynamically controlled, ebulliently cooled excursion system to use a standard relief device. The intermittent operation caused by the inherent capacity-pressure drop response (C_v curve) of this type of device could cause premature failure of the valve, piping, or process equipment. It may not be reliable for a second excursion without removal and retesting.

In cases where design is based on a closed (partially vented) system condition and the relieving equipment is expected to provide an exhaust path for ebullient cooling, the process generally requires a secondary and parallel relief equipment for an unanticipated process excursion with the vent-to-mass area ratio similar to primary relief devices. It is not evident whether the offgas exhaust attached to the thermosiphon evaporator has a secondary and parallel relief system for unanticipated process excursions.

A study of approximately 13,000 relief valves from chemical and petrochemical industries indicate that 13 percent opened at more than 110 percent of their set pressure and 3 percent never engaged (Smith, 1995). In addition, relief valves can be fouled with solids and crystallization products that restrict or plug the injection of water in the evaporator. The effectiveness of valves for the proposed aqueous injection system is uncertain.

The proposed safety controls to suppress red oil runaway reaction by isolating steam and activating aqueous injection may not be available and reliable upon demand during the time period when the highly energetic runaway reactions may limit or restrict aqueous injection in the evaporator.

3.3.3 Offgas System

The 20-percent safety margin in the off-gas control system may not be adequate to remove heat via evaporative cooling during a red oil event. During a failure of the process (temperature) control system, the vent size of the thermosiphon evaporator could allow both temperature and pressure to increase steeply in a short time due to exothermic reactions accompanied by a large increase in the volume of reaction products, and therefore increase overall risk.

3.3.4 Use of Diluents

DCS has proposed using saturated noncyclic diluents to minimize the degradation of diluents in radioactive environments. The proposed use of a saturated noncyclic diluent, such as HPT, by DCS is adequate; cyclic diluents usually degrade in radioactive environments and may initiate red oil runaway reactions at a lower temperature. In addition, DCS has proposed to implement diluent washing by the use of either pulsed columns or mixer-settlers to preclude the transfer of bulk organic quantities to heated equipment. However, diluent washing systems were not credited as PSSC. From the information provided by DCS (2001, including change pages), it is not evident whether DCS plans to conduct periodic monitoring for degradation products and assaying prior to introduction into the evaporators.

3.4 Use of RAGAGEP

There are no regulatory standards for handling reactive chemicals. This lack of definitive guidelines is likely to remain for years to come. In October 2005 a large group of academic scholars, government regulators, and industrial leaders (about 200 experts) met at the Mary Kay O'Conner Process Safety Symposium in College Station, Texas, to discuss the potential sharing of reactive chemical data via a National Science Foundation funded database. No consensus could be reached and the proposal was tabled after several hours of heated discussion. The key roadblocks were liability issues and lack of standards in reactive chemicals testing procedures. Another prevailing issue is the accuracy of available data relative to the rapidly progressing instruments and data analysis tools that are being used in recent months and years. Most data are constantly being regenerated with more advanced calorimetery to obtain improved models and guidelines for safe designs and operational practices. It was also noted that many mixtures of interest can accelerate or decelerate to a self-heating rate by several orders of magnitude due to impurity levels in the low parts per million. This phenomenon has been observed on "pure" compounds as well as mixtures, further increasing concern regarding data sharing among companies, agencies, and universities. Both

Occupational Safety and Health Administration (OSHA) and the U.S. Environmental Protection Agency (EPA), however, have adopted RAGAGEP.

RAGAGEP appears in OSHA regulation titled Process Safety Management of Highly Hazardous Chemicals—29 CFR 1910.119. Specifically, it states

> 1910.119(d)(3)(ii)—The employer shall document that equipment complies with recognized and generally accepted good engineering practices.

RAGAGEP also appears in EPA regulation titled Chemical Accident Prevention Provisions—40 CFR Part 68. Specifically, it states

> 68.56(d)—The owner or operator shall perform or cause to be performed inspections and tests on process equipment. Inspection and testing procedures shall follow recognized and generally accepted good engineering practices. The frequency of inspections and tests of process equipment shall be consistent with applicable manufacturers recommendations, industry standards or codes, good engineering practices, and prior operating experience.

RAGAGEP has been adopted in voluntary consensus standards such as Responsible Care Process Safety Code by the American Chemistry Council. These regulations and standards provide a RAGAGEP framework. The details are found in consensus standards, recommended practices and guidelines. For example, HARSNET provides guidance for establishing process controls for highly reactive chemical systems.

Since the memorandum of understanding between OSHA and NRC gives authority to NRC to conduct chemical safety evaluations for conditions leading to potential nuclear accidents, the implementation of RAGAGEP for highly reactive chemical systems warrant the same level of attention as NRC guidance. Feedback may be provided by NRC to OSHA, as appropriate.

The OSHA regulation was developed to avoid catastrophic accidents after the Bhopal accident at the Union Carbide facility in India. According to the U.S. Chemical Safety and Hazard Investigation Board (2002), reactive chemical accidents are a major safety problem. However, the report was not able to quantify the extent of the problem because only a limited number of accidents specific to certain chemicals were OSHA-reportable. The report identified 167 reactive chemical accidents in the past 20 years that claimed 108 lives (an average of 5 lives per year).

Selection of maximum operating temperature and vent size for thermosiphon evaporators for acid recovery and oxalic acid destruction are not based on accepted practices currently adopted at the H-Canyon facility at the SRS and recommended by the DNFSB.

3.5 Additional Research

DCS has proposed to conduct additional research on the following.

(1) Runaway initiation temperature
(2) Effect of impurities on initiation temperature

Additional research on runaway initiation temperature is a very broad topic. Details are needed to evaluate whether DCS research plans would provide sufficient insights on red oil runaway reactions. A possible scenario for a red oil runaway reaction includes the contribution of the interfacial reaction between organic and aqueous phases at equal mixing (kinetic energy dissipation) levels encountered in a thermosiphon evaporator. Prevention of organic phases contacting an acid aqueous phase could provide an insufficient safeguard. Furthermore, more testing may be needed to derive the minimum temperature at which self-heating starts. However, DCS has included the presence of organics in the unit operations and therefore the components of the unit operation requires supplementation with mitigation solutions, such as an open system relief path design.

Assuming a perfect research plan, execution, and a resulting perfect data set of red oil thermo kinetics, it is not evident how the new knowledge would be incorporated in to the process design so that it improves the operational safety margin for an evaporator with a closed system relief design that is operating at a design basis temperature of 125 °C [257 °F].

3.6 Backfit Options

The CNWRA preliminary assessment of the PSSC classification shows that a red oil event could be classified as a not-unlikely high-consequence event. Therefore, the PSSC adopted by the DCS for preventing a red oil runaway event for the closed thermosiphon evaporators may not be adequate. In this context, the CNWRA staff examined backfit options following construction authorization. Results are summarized in Table 3-1.

Options 1 to 3 provide effective solutions to avoid extensive retrofit without significant potential construction cost implications.

Review of similar facilities ($3 billion or more) in the commercial non-nuclear industry indicates no generally accepted rules-of-thumb for defining a costly backfit as a fraction of total plant investment. Industrial investments are made on a risk-reward basis relative to product profits anticipated. Furthermore, it is difficult to find private facilities of this investment scale that are not relatively risk free, from a technology and design basis, through long-term operations and scale-up from smaller facilities over decades of commercial experience. To date, there are no similar examples for NRC licensed facilities under 10 CFR Part 70.

3.7 Summary

There is very limited information in the open literature on the preventive or mitigative solutions that are adopted by other facilities that can be used to review the proposed DCS methodology for preventing red oil runaway reactions. According to a DNFSB report (Conway, 2003), the H-Canyon facility at SRS is designed

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- To control the TBP mass by using a mixture of 7.5 percent TBP organic mixture (DCS plans for 30-percent TBP, which is less conservative comparted to the Canyon facility)

Table 3-1. Backfit Options and Potential Cost Implication to Prevent Red Oil Runaway Reactions in Closed Thermosiphon Evaporators. Only Capital Costs Are Considered.

Number	Backfit Option	Potential Construction Cost*/Efficiency Implication
1	Reduce operating and maximum bulk fluid temperature to provide a sufficient safety margin (i.e., below the onset of exothermic reactions plus safety margin).	No substantial cost implication. Significant reduction in process efficiency.
2	Increase the vent size of thermosiphon evaporators to meet open-system requirements.	Cost associated with engineering design change. Marginal reduction in process efficiency.
3	Install secondary and parallel independent pressure relief system to thermosiphon evaporators for unanticipated process excursions exceeding the design temperature. The vent area/organic mass for this relief system should meet open thermosiphon evaporator requirements.	Cost associated with engineering design change, installation of additional equipment (pressure relief and associated control systems). Process efficiency could be maintained.
4	Rigorous control on the amount of organic mass that could enter thermosiphon evaporators.	Cost associated with engineering design changes, installation of monitoring and chemical analyses systems. A mechanism to handle out-of-specification feed stock. Process efficiency could be compromised.
5	Conduct additional research to show that the red oil runaway reaction temperature of 134 °C [273 °F] is conservative. This approach would need to consider that the presence of impurities could further reduce the red oil runaway reaction temperature.	Results unknown. Could provide new insights in understanding red oil runaway reaction.

*Costs were not considered in detail due to the preliminary nature of the information available in the Duke Cogema Stone & Webster Construction Authorization Request. The Center for Nuclear Waste Regulatory Analyses engineering judgement indicates that these costs would not be a substantial component of the total facility costs.

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- For the evaporator to have an over-temperature set point at (b)(2)High [redacted] (b)(2)High [redacted]
- With passive vent size
- For regular inspection of storage tanks for organic layers and skimming of accumulated organic layers—no such inspections are discussed by DCS
- To concentrate dilute solutions to 50 percent nitric acid (DCS plans to concentrate nitric acid to 13.6 N, which is less conservative comparted to the Canyon facility)

The proposed DCS design philosophy excludes

- Use of a rupture disk that could provide an additional layer of protection to limit the consequences of runaway reaction leading to an explosion (mitigative)
- Use of pressure control system that may provide an additional indication for runaway reaction (mitigative)
- Use of a larger vent size to limit the over pressurization in the thermosiphon evaporators (preventive)
- Control on organics in the process flowsheet. Inadvertent transfer of organics to concentrated nitric acid solutions at high temperature is considered an expected event (preventive)

The use of a larger vent size for thermosiphon evaporator is not addressed in the design basis/construction. Whereas this is not an expensive backfit, it could reduce the consequences from not unlikely to highly unlikely. The CNWRA review does not indicate any cost prohibitive backfits. However, reliable temperature and pressure controls would help to ensure that the temperature does not exceed decomposition of TBP to butene at 150 °C [302 °F] that could cause detonation.

4 CONCLUSIONS

The CNWRA assessment, based on the review of the PSSC and the proposed preventive and mitigative solutions indicates that red oil runaway reactions could be classified as not-unlikely high-consequence events. The PSSC adopted by the DCS for preventing a runaway red oil event for the closed thermosiphon evaporators may not be adequate. However, review of the potential backfit options indicates that effective solutions can be obtained without extensive retrofit and without significant potential construction cost implications

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APPENDIX A

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APPENDIX B

HAZARD ANALYSIS SUMMARY BY PROCESS SECTION

This quantitative analysis of each process section is based on the kinetic theory of chemical reactions. The rate of a chemical reaction, such as the hydrolysis of tributyl phosphate, is the first derivative of concentration with respect to time. Therefore, the relative quantity of chemical that is transformed due to reaction is proportional to the product of the rate and residence time. The energy release is proportional to the amount of chemical transformed times the heat of reaction. The rate is calculated from the product of the chemical concentrations, catalyst concentrations, and a kinetically weighted temperature as shown in Table B–1. The kinetically weighted temperature is determined as a product frequency factor and the exponential of the activation energy divided by the universal gas constant, R and the absolute temperature. This product of rate and residence time is proportional to the probability of occurrence or hazard index associated with a given unit operation or section of the process. The higher the hazard index, the higher the probability of a red oil event.

A ranked pictorial representation of the relative likelihood of an auto-thermal event due to the red oil chemistry occurring in a given section of the aqueous polishing process is illustrated in Figure B–1. Figure B–1 is based on the data in Table B–1. It can be seen that this method of analysis is strongly influenced by the temperatures inside a given section of the process. This analysis cannot predict the possibility of a trapped organic phase in a high residence intermediate storage vessel containing high acid concentration. For cases other than this extremely hazardous scenario chemical kinetic theory is reliable indicator of the hazardous potential of a given section of the process relative to other parts of the process. A more detailed application of chemical kinetic theory at the process unit operation level could provide a method to evaluate specific hazards inside each process section. To apply such an analysis, process details at the material balance flowsheet stage of design would be required.

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ATTACHMENT 6 to Panel Report

LIST OF ACRONYMS

ACRS	Advisory Committee on Reactor Safeguards
ALARA	As Low As Reasonable Achievable (used only in strike out area)
CAR	Construction Authorization Request
CFR	Code of Federal Regulations
CNWRA	The Center for Nuclear Waste Regulatory Analysis
DCS	Duke Cogema Stone & Webster
DNFSB	Defense Nuclear Facility Safety Board
DOE	Department of Energy
DPO	Differing Professional Opinion
EPA	Environmental Protection Agency
FCSS	Fuel Cycle Safety and Safeguards
FSAR	Final Safety Analysis Report
FSER	Final Safety Evaluation Report
HPT	Hydrogenated Propylene Tetramer
ISA	Integrated Safety Analysis
MD	Management Directive
MOX	Mixed Oxide
NMSS	Office of Nuclear Material Safety and Safeguards
NRC	Nuclear Regulatory Commission
OSHA	Occupational Health and Safety Administration
PSSC	Principal Structures, Systems, and Components
RAGAGEP	Routinely Accepted or Generally Accepted Good Engineering Practices
RDSER	Revised Draft Safety Evaluation Report
SECY	Secretary of the Commission, Office of the (NRC)
SER	Safety Evaluation Report
SNM	Special Nuclear Material
SRP	Standard Review Plan
SRS	Savannah River Site
TBP	Tributylphosphate
TEDE	Total Effective Dose Equivalent