FACILITY RISK REVIEW OF A URANIUM PROCESSING COMPLEX: A RISK-INFORMED DECISION-MAKING PROCESS

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ABSTRACT

This paper discusses the facility risk review (FRR) of an operating uranium processing complex and the National Nuclear Safety Administration (NNSA) local and Chief of Defense Nuclear Safety (CDNS) perspectives on using an analytical hierarchy process (AHP) to make risk-informed decisions. The CDNS staff selected the AHP as the preferred tool for risk-informed decision making, and the FRR was a pilot study for use of the AHP. The results of this pilot study will be discussed in this paper.

The purpose of the FRR is to identify the upgrades necessary to ensure continued safe operations of the existing uranium processing facility for an additional 15 years. (The remaining life of the complex is expected to be 15 years.) The study evaluated postulated accident scenarios involving safety systems and important defense in-depth systems. Any "gaps" between expected performance/credited functional performance criteria and existing conditions were identified, and recommended system upgrades and/or compensatory measures were proposed. The AHP was used to prioritize the moderate and high risk events from either a safety or manufacturing aspect in order to develop recommendations.

INTRODUCTION

The risk-informed analysis is consistent with the draft DOE policy, *Department of Energy Risk Assessment Policy,*[a] which follows the guidance in draft DOE G 421.1-2, *Risk Management Planning and Execution Guidance.*[b] The technique used was the facility risk review (FRR) (also called a preliminary risk analysis, as described on the U.S. Coast Guard risk-based decision-making [RBDM] Web site: http://www.uscg.mil/hq/g-m/risk/e-guidelines/pra.htm). An FRR characterizes risks associated with different parts of a facility, using screening techniques that focus only on the highest risk events. FRR is a simplified approach to accident-based risk assessment, with the main goal being to define the risk related to important accident scenarios. This team-based approach relies on subject matter experts examining the issues. The team suggests possible accidents, most important contributors to accidents, and protective features.

The FRR identified (1) the risk of the accidents and manufacturing outages and (2) recommendations for reducing the risk. The goal was to characterize the baseline risks associated with operations in the uranium processing complex. The FRR team focused on the safety aspect of the risk of the uranium processing complex attributed to accidents that affect the (1) facility

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[a] *Department of Energy Risk Assessment Policy*, DRAFT – to be issued.
[b] DOE G 421.1-2 *Risk Management Planning and Execution Guidance*, DRAFT – to be issued.

workers and (2) offsite public (assumed to be at the Emergency Response Boundary [ERB]). The FRR team developed a risk matrix that uses frequency and consequence bins. The results should be interpreted as relative results and used for comparison of proposed recommendations to improve the risk. The results are based on best-estimate frequency and consequence values with enough precision to justify order-of-magnitude bins. Risk scores in a matrix associated with the different activities were used to sort the current risk. The FRR team evaluated a baseline case and an extended case, assuming the facility is operating for another 15 years.

As much as possible, the existing, submitted safety analysis documentation was used to (1) identify the applicable operating areas, (2) identify the accidents, and (3) categorize the risk. The risk of failure was estimated through safety analysis and expert elicitation. The safety documentation presents potential consequences for which each of the safety systems, structures and components (SSCs) is credited. Expert elicitation was used to determine the estimated frequency of failure of the SSCs when needed to perform the safety function for which they are credited. This included estimating the initiating event likelihoods and system failure probabilities. The frequency values were considered a 50-percentile, best estimate. As applicable, the frequency of initiating events and the failure rate of SSCs were presented for the current case (no degradation) and for the case 15 years in the future (assuming degradation). With this information, the relative ranking of accidents involving various SSCs is displayed. The output of this FRR are (1) a prioritized list of risks of the postulated accidents and (2) a list of how the failures of the various SSCs affect the risk, which in turn affects both safety and manufacturing.

APPROACH

This FRR was performed in three steps.

- **Step I** – Assess the preliminary quantitative risk of safety mishaps that involve failure of the analyzed SSCs

- **Step II** – Evaluate the manufacturing risk associated with known deficiencies and potential failures that affect the capability to meet production and material at risk (MAR) reduction goals

- **Step III** – Determine the areas on which risk reduction emphasis should be placed and suggest a priority for performing upgrade planning based on the risks determined during this process

For Step I of this analysis, the stakeholders were particularly interested in the SSCs that have already been designated as safety significant or safety class in the current safety basis documentation. The team decided to restrict Step I of the FRR to these SSCs. For Step II, the manufacturing and support systems needed to meet production goals and to reduce MAR were emphasized. In Step III, the results of Steps I and II were combined to obtain a (1) prioritized listing of the overall risks of the uranium processing complex and (2) listing of the proposed projects to address the identified risk.

Ultimately, the key objective was to use a risk-based decision-making process to identify the upgrades to ensure continued safe operations in the uranium processing complex for the next 15 years.

The purpose of Step II was to evaluate the process system's operational reliability that may prevent two of the primary functions from being accomplished. The evaluation period of 15 years is the time frame for a replacement facility to be designed, constructed, and transitioned to full operation status. The two process functions being evaluated are uranium material recovery and uranium part production.

Step III identified a risk acceptance level for each of the risk matrices from Step II. Using weighted evaluation criteria, the moderate and high risk events were then prioritized. The AHP is a formal decision-making process that uses pairwise comparisons of each project against the other projects. Specialized software was used with trained facilitators to record the scores and calculate the final results. Step III produced a prioritized project list. The prioritized project list is the recommended investments to continue safe operation of the uranium processing complex for the next 15 years.

STEP I APPROACH – SAFETY RISK RANKING

The analysis identified the risk of the accidents and recommendations for reducing risk. The goal was to characterize the baseline risks associated with operations in the uranium process complex. The FRR team focused on the safety aspect of the risk of the uranium processing complex attributed to accidents that affect the (1) facility workers and (2) offsite public (assumed to be at the ERB). The FRR team developed a risk matrix that uses frequency and consequence bins. Risk scores affecting the different activities were used to sort the risk as it currently exists. The team evaluated a baseline case and an extended case, assuming the facility is operating for the next 15 years.

Where possible, the existing, submitted safety analysis documentation for the complex was used to (1) identify the applicable operating areas, (2) identify the accidents, and (3) categorize the risk. The risk of failure was estimated through safety analysis and expert elicitation. The safety analysis presents potential consequences for which each of the safety SSCs are credited. Expert elicitation was used to determine the estimated frequency of failure of the SSCs when needed to perform the safety function for which they are credited. This included estimating the initiating event likelihoods and system failure probabilities. The frequency values were provided as a 50-percentile, best estimate. As applicable, the frequency of initiating events and the failure rate of SSCs were presented for the current case (no degradation) and for the case 15 years in the future (assuming degradation). With this information, the relative ranking of accidents involving various SSCs were displayed. The output of this FRR was a (1) prioritized list of risk of the postulated accidents and (2) list of how the failures of the various SSCs affect the risk. The base results assumed continuing operation for 15 years.

The determination of the risk to safety SSCs and manufacturing processes was performed in the following process steps:

1 – Determine the scope of the FRR
2 – Screen low risk activities and accidents
3 – Analyze accidents
4 – Generate a risk profile
5 – Use the risk profile in decision making (Step III)

These tasks are consistent with the tasks outlined for an FRR on the U.S. Coast Guard Web site http://www.uscg.mil/hq/g-m/risk/e-guidelines/pra.htm.

Figure 1 is the risk matrix used to display the safety and manufacturing risks identified in Steps I and II.

STEP II APPROACH – MANUFACTURING (PRODUCTION RISK AND MAR REDUCTION) RISK

For the manufacturing (production and MAR reduction) portion of the FRR (Step II), the same tasks used to evaluate the safety risks were used to evaluate the manufacturing (production and MAR reduction) risk. The output of Step II was presented so that the results were compared with the results of Step I. The FRR approach depended on two separate factors, the first being the frequency of the event and the second being its consequences (i.e., impact to mission). The underlying causes preventing sustainable manufacturing operations in the uranium processing complex were identified. This effort was forward-looking, anticipating future problems from aging equipment and identifying the necessary actions to preclude the aging impacts. Potential impacts from utility and support systems were also included in the scope if failure of the system directly impacted manufacturing operations or facility habitability. In addition, this effort considered impacts from personnel resource availability. The manufacturing risk matrices were used to perform a risk ranking of manufacturing risk, based on equipment downtime and MAR reduction. Based upon these risk rankings, along with the safety risk rankings, the risk management prioritized project list (Step III) (1) identified proposed equipment upgrades and (2) improved maintenance frequency or other upgrades/modifications to achieve sustainable operations to reduce overall risk in the uranium process complex by reducing material at risk and/or changing forms of materials and storage locations.

The primary forms that contributed to the consequences analyzed in the accident analysis included aqueous/organic solutions and metals/oxides. (Materials that are in process equipment were excluded from this evaluation because they are assumed to be within the baseline for the facility.) The bulk quantity of aqueous/organics solutions was low but due to their high airborne release fraction they were a significant contributor to facility consequences for large events that involve multiple storage areas. The uranium material recovery function is required to transform this material from its existing form to a form suitable for use or storage. The metals/oxides have a significantly lower airborne release fraction, but due to the large in-process inventories they also can have a large consequence if an event involves a large area. A new storage facility will be available shortly to absorb the storage load of certain forms of enriched uranium.

<table>
<tr><th colspan="3">Consequence Categories</th><th>F</th><th>E</th><th>D</th><th>C</th><th>B</th><th>A</th><th colspan="2"></th></tr>
<tr><td colspan="3">Facility Worker Consequences</td><td><0.1SI/D</td><td>$0.1\leq$SI/D<0.3</td><td>$0.3\leq$SI/D<1</td><td>$1\leq$SI/D<3</td><td>$3\leq$SI/D<10</td><td>≥10SI/D</td><td colspan="2"></td></tr>
<tr><td colspan="3">Public Consequences</td><td>Negligible</td><td>Tc$<$ERPG-1
Rc<0.1 rem</td><td>ERPG-1$\leq$Tc$<$ERPG-2
0.1 rem$\leq$Rc<1 rem</td><td>ERPG-2$\leq$Tc$<$ERPG-3
1 rem$\leq$Rc<5 rem</td><td>ERPG-3$\leq$Tc$<$ $10\times$ERPG-3
5 rem$\leq$Rc<100 rem</td><td>Tc$\geq10\times$ERPG-3
Rc≥100 rem</td><td colspan="2"></td></tr>
<tr><td rowspan="6">Safety Risk Frequency (F) Category</td><td>5</td><td>$F\geq10^{-2}$/yr</td><td colspan="2" rowspan="2">High/Low</td><td colspan="2" rowspan="2">High/Moderate</td><td colspan="2" rowspan="2">High/High</td><td rowspan="2"><i>High – Expected to happen</i></td><td rowspan="6"><i>Manufacturing Risk Frequency (F) Category</i></td></tr>
<tr><td>4</td><td>10^{-3}/yr $\leq F<10^{-2}$/yr</td></tr>
<tr><td>3</td><td>10^{-4}/yr $\leq F<10^{-3}$/yr</td><td colspan="2" rowspan="2">Moderate/Low</td><td colspan="2" rowspan="2">Moderate/Moderate</td><td colspan="2" rowspan="2">Moderate/High</td><td rowspan="2"><i>Moderate – May or may not happen</i></td></tr>
<tr><td>2</td><td>10^{-5}/yr $\leq F<10^{-4}$/yr</td></tr>
<tr><td>1</td><td>10^{-6}/yr $\leq F<10^{-5}$/yr</td><td colspan="2" rowspan="2">Low/Low</td><td colspan="2" rowspan="2">Low/Moderate</td><td colspan="2" rowspan="2">Low/High</td><td rowspan="2"><i>Low – Not expected</i></td></tr>
<tr><td>0</td><td>$F\leq10^{-6}$/yr</td></tr>
<tr><td colspan="3"><i>Material Recovery</i></td><td colspan="2"><i>Low - < 3 months delay</i></td><td colspan="2"><i>Moderate – 3 months to 6 months</i></td><td colspan="2"><i>High – 6 months and greater delay</i></td><td colspan="2"></td></tr>
<tr><td colspan="3"><i>Metal Parts Production</i></td><td colspan="2"><i>Low - < 5 days delay</i></td><td colspan="2"><i>Moderate – 5 days to 30 days delay</i></td><td colspan="2"><i>High – 30 days and greater delay</i></td><td colspan="2"></td></tr>
<tr><td colspan="3"><i>Facility Op/Process Support</i></td><td colspan="2"><i>Low - < 5 days delay</i></td><td colspan="2"><i>Moderate – 5 days to 15 days delay</i></td><td colspan="2"><i>High – 15 days and greater delay</i></td><td colspan="2"></td></tr>
</table>

Figure 1 Risk Matrix (Safety and Manufacturing Risk).

Figure 2 provides a representation of the inventory of the different materials of concern over the evaluation period for the facility. The different lines should not be compared between the aqueous/organics and the metals/oxides. Figure 3 provides a representation of the airborne release source-term fraction from the different material forms over the evaluation period for the facility.

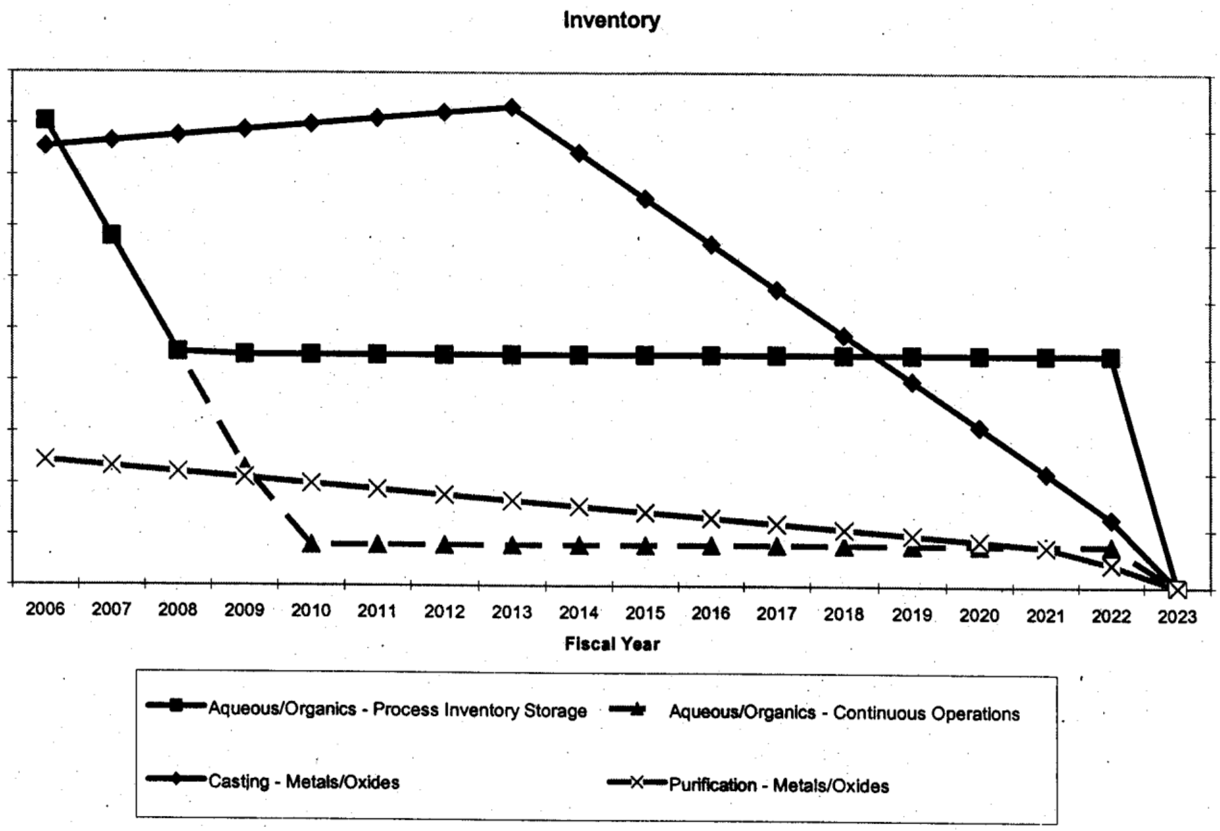

Figure 2 Representation of the Potential Inventory of Different Materials Within the Facility (scale not provided).

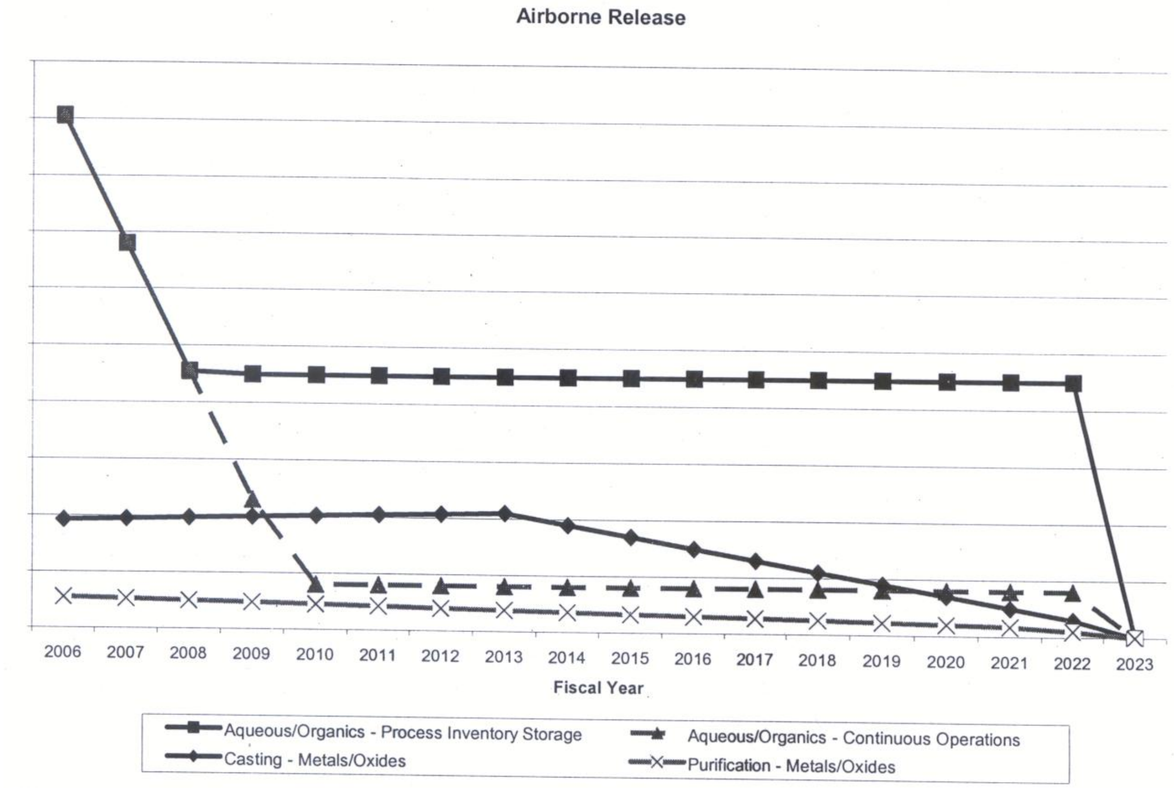

Figure 3 Comparison of the Contribution to the Airborne Release of the Different Process Materials Being Evaluated.

STEP III APPROACH – PRIORITIZED PROJECT LIST

Based on the results from Steps I and II, the risk management prioritized project list (RMPPL) was developed using the AHP. The AHP methodology was selected because it is formal and structured and allows the use of quantitative and qualitative criteria when ranking projects. AHP puts the quantitative and qualitative criteria in the same decision context by relying on relative comparison instead of attempting to define absolutes. Humans are more capable of making relative judgments than absolutes, so AHP, using the pairwise comparison technique, is relatively simple to execute.

> "AHP is a systematic procedure for representing the elements of any problem hierarchically. It organizes the basic rationality by breaking down a problem into its smaller and smaller constituent parts and then guides decision makers through a series of pairwise comparison judgments (which are documented and can be reexamined) to express the relative strength or intensity of impact of the elements in the hierarchy. The AHP includes procedures and principles used to synthesize the many judgments to derive priorities among criteria and subsequently for alternative solutions."[c]

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[c] Thomas L. Saaty and Kevin P. Kearns, *Analytical Planning*, RWS Publications, Pittsburgh, PA, 1985.

The AHP tool evaluates alternatives in a formal manner, balancing the different risks of continuing operations in a facility. By reducing complex decisions to a series of pairwise comparisons, then synthesizing the results, AHP not only helps decision makers arrive at the best decision, but also provides a clear rationale for the decision. With the problem statement for this review defined as “What investments are required to continue safe operations in the uranium processing complex for 15 years?,” the next step was to identify evaluation criteria for prioritizing the projects. Once evaluation criteria were identified, the team used AHP pairwise comparisons to weigh the criteria. The pairwise comparisons were performed by comparing each criterion against the other criterion. For example, if criterion A was much more important compared to criterion B, then criterion B had a value of 1/5 compared to criterion A. Thus, for each comparative score given, the reciprocal was awarded to the opposite relationship. The normalized weight was then calculated for each criterion, using the geometric means of the scores for the criterion against the other criterion, divided by the sum of the geometric mean of all criteria.

Trained facilitators guided the FRR team through the AHP process, using specialized software. The software made possible the synthesis of input from multiple stakeholders and provided the necessary capability to analyze, prioritize, and communicate those decisions. The software allowed the stakeholder team to score the criteria and alternatives and to see the results immediately, with many graphical formats. The software allowed individual scoring, which was then averaged, or a single score based on team consensus. The team consensus approach was used to develop the RMPPL. This approach allowed (1) all team members to voice the basis for their scoring and (2) an ensuing discussion that assisted team members to evaluate all inputs. The benefit of this approach was that consensus was reached after all inputs were heard. The potential weakness of this approach was that team members who were not comfortable voicing their concerns may have allowed the scoring to be skewed. Based on the geometric mean from the AHP, the software provided a mathematically rigorous application and proven process for prioritization and decision making. The AHP software made it easier to perform a sensitivity analysis of the results. Sensitivity analysis was performed by varying the weights of the evaluation criteria by 10% (in both directions) and determining if the results varied. If the results did not vary the overall results, then the analysis was considered robust. The AHP software tracked the consistency of scores, identifying if there were scores that were mathematically inconsistent with other scores. An overall consistency score of < 0.1 was considered good.

The NNSA CDNS requested that the NNSA site office pilot use AHP as a risk-informed decision-making tool. The CDNS observed the execution of AHP for developing the RMPPL. One of the lessons learned from the pilot activity was that strong team leadership is required if team consensus is to be reached while ensuring all voting team members are inputting their position on the scoring.

The evaluation criteria were defined as follows by the FRR team:

1. Safety: Maximum Safety Benefit
2. Operations: Maximum Operational Reliability
3. Cost: Minimum Implementation Cost

4. Duration: Maximum Duration of Benefit
5. Impact: Minimum Impact to Operations During Implementation

Pairwise comparisons were performed to weigh the evaluation criteria.

OBSERVATIONS AND CONCLUSIONS

STEP I (SAFETY RISK) OBSERVATIONS AND CONCLUSIONS

When using the FRR data to perform a relative risk ranking for the Step I results (the base case [i.e., year 2006] risk of the various accident scenarios), the leading accidents were various seismic and fire accident scenarios for both the facility worker consequences risk matrix and the public consequences risk matrix. For the facility worker seismic scenarios, many represented office areas where there were no significant quantities of radiological and/or toxicological materials. From the fire accident scenarios, a key assumption in minimizing the potential impact on facility workers was the assumption that workers can and will evacuate the area before they are affected by the radiological and/or toxicological hazards. The 15-year aging case resulted in an increase in the frequency category by a bin for fires in areas protected by dry pipe sprinkler systems. Excluding the fire scenarios, the risk results for the various credited SSCs did not dominate the risk for either facility workers or the public.

The FRR technique provided a systematic process for determining the risk of various accidents within the uranium processing complex. The results should be interpreted as relative results and used for comparison of proposed recommendations to improve the risk. The results are based on best-estimate frequency and consequence values with enough precision to justify order-of-magnitude bins. This information can then be used to (1) determine where risk reduction actions are necessary and (2) help prioritize planning through the risk-based allocation of resources (Step III).

STEP II (MANUFACTURING RISK) OBSERVATIONS AND CONCLUSIONS

Generic issues appeared in Step II of the FRR. The primary generic issues were maintenance capacity and critical spare parts. Step III established a project plan to address these generic issues and specific issues with the results of Step I.

One of the primary recommendations from the evaluation was to increase the maintenance capacity within the facility and procure spare equipment for critical systems and long lead items. This recommendation was primarily supported by the current age of the facility and process equipment. The facility and its structures are more than 50 years old, some originally dating to the early 1940s. Most of the process equipment and support systems are more than 30 years old, with some equipment being significantly older. The design and operational life of the equipment have been exceeded, thus requiring additional corrective maintenance to maintain it in a functioning condition. Several deficiencies have occurred that prevent operating the processes and/or support systems. The current resource level has been adequate to maintain some systems operational and to meet immediate or ‘critical’ operational needs, typically only supporting the near-term mission.

Previous operational history has demonstrated additional maintenance support is required to maintain the facility in an operating condition and promptly responding to deficient conditions when they occur. With the application of the required maintenance capacity, the required deficiencies can be worked off and allow a transition to predictive and preventive maintenance.

STEP III (AHP) OBSERVATIONS AND CONCLUSIONS

When evaluating the problem statement of identifying what investments are necessary to continue safe operations in the uranium processing complex for 15 years, it was clear there were competing interests and priorities. For example, it is a high priority to (1) continue to support the nuclear weapons stockpile, (2) work for others, and (3) provide other customers with the products they need. However, at the same time, the safety priority requires investments in material recovery operations, which involve different process equipment than what is needed to support the metal production mission requirements. With limited resources, cost is a factor and with limited remaining life of the complex, scheduling is important. AHP allowed for integrated and structured risk ranking of the projects to address the risks identified in Steps I and II. In order to effectively integrate the differing priorities, it was necessary to make relative comparisons using the pairwise comparison technique. Application of the AHP provided a structured risk analysis tool by breaking each scoring down to the smallest component with relative comparisons.

In conclusion, the AHP successfully prioritized projects to address the risks of continuing operation in the uranium processing complex for 15 years. The highest priorities for investments in the complex to address the risks of continuing operations for 15 years are (1) increased maintenance resources and procurement of critical spare parts, (2) replace/repair portions of the tower water and steam systems, (3) replace multiple electrical components/panels, and (4) replace/upgrade ventilation systems. The FRR team recommends, based on the acceptance of risks in the low consequence or frequency bins for Steps I and II, that all of the projects on the RMPPL be funded and completed starting in FY09. Larger investments in the first few years will allow the majority of the projects to be completed, thus improving the risk profile of the facility and gaining the most duration of benefit from the projects.