Risk Management Considerations for Seismic Upgrading of an Older Facility for Short-Term Residue Stabilization

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Building 707 and its addition, Building 707A, were selected, after the production mission of Rocky Flats was terminated a few years ago, to stabilize many of the plutonium residues remaining at the site by 2002. The facility had undergone substantial safety improvements to its safety systems and conduct of operations for resumption of plutonium operations in the early 1990s and appeared ideally suited for this new mission to support accelerated Site closure. During development of a new authorization basis, a seismic evaluation was performed. This evaluation addressed an unanalyzed expansion joint and suspect connection details for the precast concrete tilt-up construction and concluded that the seismic capacity of the facility is less than half of that determined by previous analysis. Further, potential seismic interaction was identified between a collapsing Building 707 and the seismically upgraded Building 707A, possibly causing the partial collapse of the latter. Both the operating contractor and the Department of Energy sought a sound technical basis for deciding how to proceed. This paper addresses the risks of the as-is facility and possible benefits of upgrades to support a decision on whether to upgrade the seismic capacity of Building 707, accept the risk of the as-is facility for its short remaining mission, or relocate critical stabilization missions. The paper also addresses the Department of Energy’s policy on natural phenomena.

The evaluation approach first established what was known and what uncertainties remained regarding the current structural capacity of the facility. Further, the increase in capacity that could be attained through a practical upgrade concept, which focused on accessible portions of the facility’s lateral force resisting system, was estimated. These upgrades, which could be implemented at a cost of about $4M, would increase the facility seismic capacity to its previously determined level (but not to current Performance Category 3 requirements) without physically interfering with the risk reduction activities in the facility.

The increased risk to the public and facility workers from this discovery was evaluated and concluded to be an unreviewed safety question due to the increase in consequences and frequency. Previous estimates of risk to the public had identified that the seismic risk to Building 707/707A dominates the overall Site. To determine if this increased risk would be so high as to require mitigation regardless of cost or schedule impact, comparisons were made to other Site risks, to the Department of Energy SEN-35 Safety Goals, and to the historical risk perspective underlying restart of the facility in 1993, along with uncertainties in the risk estimates. Habitability of the structure for facility workers is a life safety issue that also needed to be addressed prior to initiating cost/benefit analyses.

Cost/benefit studies were then performed to assess the identified practical upgrades. The studies used a model developed by the Federal Emergency Management Agency. The probabilistic or “expected” savings from the upgrades were compared with the upgrade cost for a base case and a broad range of uncertainties involving impact magnitudes, structural upgrade benefits, and mission duration (remaining
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facility life). The damage model required inputs on the degree of facility damage at various earthquake sizes and corresponding impacts on public and worker health, loss of equipment, mission risks (loss of capability or substantial delays), and environmental risks.

Introduction

The Building 707 and its addition, Building 707A, were selected a few years ago to stabilize by 2002 many of the plutonium residues remaining after the plutonium pit production mission of Rocky Flats was terminated in 1992, and to stabilize plutonium metal and oxides for interim storage per the commitments made in response to Defense Nuclear Facilities Safety Board Recommendation 94-1. The facility was built in the early 1970s with tilt-up, precast concrete twin-tee construction. Figure 1 illustrates the general layout of the two structures. Building 707A was structurally upgraded in the 1992 to increase it’s seismic capacity and reduce risk to the public. The facility had undergone substantial safety improvements to its safety systems and conduct of operations for resumption of plutonium operations in the early 1990s and appeared ideally suited for this new mission to support accelerated Site closure (i.e., Site closure by 2006 to 2010). Once the residue stabilization mission is completed, the facility is to be decommissioned.

Figure 1. Layout of Buildings 707 and 707A

The preparation process included development of a new authorization basis and determination of the structural impact of an expansion joint that had been overlooked in the most recent structural evaluation for resumption of plutonium operations. Unfortunately, the new structural analysis uncovered attachment details for the tilt-up construction that resulted in the seismic capacity of the facility being less than half what it had been thought to be (i.e., the building could fail for a smaller earthquake at a much higher frequency of occurrence). Further, a potential seismic interaction was identified between a
collapsing Building 707 and the seismically-upgraded Building 707A, possibly causing the partial collapse of the latter.

Thus, Site managers were confronted with the possibility of diverting the resources necessary for upgrades from ongoing Site risk reduction activities just as the push toward Site closure was being mounted. Both the operating contractor and the Department of Energy sought a sound technical basis for deciding how to proceed. The principal options were to proceed with plutonium metal, oxide, and residue stabilization as planned (accepting the increased risk), to divert some closure resources and upgrade the building to the extent practical while stabilization was initiated, or to relocate the critical Site closure mission (accepting the cost and schedule penalty). To support the decision process, an innovative evaluation capped by a cost/benefit analysis was performed. The evaluation process considered the DOE policy for natural phenomena hazards (NPH), the structural capacities of the 707 Complex with and without upgrades, the risks of operation with and without the upgrades, and the cost/benefit ratio for the proposed upgrades.

DOE NPH Upgrading Policy

DOE Order O 420.1, Facility Safety (Reference 1), establishes policy for NPH mitigation for new facilities and evaluation of existing facilities. DOE’s policy for NPH requires design features to confine hazardous materials and to protect the workers, public, environment, property and essential functions; but, the policy also requires the evaluation of cost-effectiveness, particularly in instances of a short remaining mission such as this one. Section 4.4.1 of the Order requires that hazardous facility safety analyses address the ability of facility systems, structures, and components (SSCs) to perform their intended safety functions under the effects of natural phenomena. Section 4.4.3 requires evaluation of existing facilities for seismic capability when there is a significant degradation of the safety basis (which applies in this case) or when the Executive Order 12941 (Reference 2) requires such an evaluation. When an evaluation identifies NPH mitigation deficiencies, an upgrade plan is required with a prioritized schedule recognizing funding constraints and programmatic mission considerations. The Order also addresses re-evaluation of the Site’s NPH hazard curves every 10 years, detection capabilities for damaging seismic events, and procedures for post-seismic inspections and damage assessments, as well as requirements for the design of new facilities.

Specific criteria for evaluation and upgrade of existing facilities are provided in Section IV.3 of a draft implementation guide (Reference 3) for DOE O 420.1. Regarding the evaluation outcome, the guide states: “If the evaluation of existing SSCs identifies NPH mitigation deficiencies, the contractor/operator shall evaluate the cost/benefit of potential improvements and establish an upgrade plan for cost-beneficial improvements.”

Nationally, the Congress has begun to confront the issue of seismic risk in all federal buildings through the National Earthquake Hazards Reduction Program (NEHRP). For existing facilities this is being implemented through Executive Order 12941 that requires an assessment of the existing stock of federal facilities for seismic vulnerability and of the approximate cost of upgrading the higher risk facilities. The Federal Emergency Management Agency (FEMA) is charged with submitting their assessment in the form of “a comprehensive report on how to achieve an adequate level of seismic safety in federally owned and leased buildings in an economically feasible manner” to Congress for their consideration by December 2000. Building 707 is identified as a high risk facility within the DOE Environmental Management scope, but the FEMA submittal will assign priority to vulnerable buildings in zones of high seismicity. However, Building 707 would be excluded from priority designation since the Site is in a low seismicity region. The national program seeks to manage the upgrade process rationally based on
risk, with the Congress responsible for establishing the national priority of increased seismic safety for existing federal facilities (i.e., the level of funding to be made available). While the NEHRP focuses on life safety and does not address the incremental effects of hazardous material on risk, the approach being taken illustrates the complexity of upgrade decision making.

Structural Evaluation

The evaluation approach (Reference 4) first established what was known and what uncertainties remained regarding the current structural capacity of the facility. This evaluation was based on an updated Site Seismic Hazard Curve and new NPH criteria from DOE Standard 1020 (Reference 5) which imposed greater earthquake motions than the criteria in effect in the late 1980s when Building 707A was seismically upgraded, and when its suitability for resumption of plutonium operations was developed in the early 1990s.

The recent structural analyses performed for the new mission and new authorization basis were initiated primarily to determine the effect of an expansion joint which bisects Building 707 and effectively divides the building into two seismically independent structures. The expansion joint had not been included in prior seismic evaluations. The analyses were also performed to incorporate the most recent Site seismic hazard curves at “rock” (defined as 100 feet below the surface, the level at which the claystone shear wave velocity reaches 2000 feet/second) and to update estimates of the effect of overlying soil on amplification of motion at the surface, as required by DOE Order O 420.1 Section 4.4.4. When Building 707 was found to be significantly weaker than previous estimates, additional analyses were undertaken to determine whether the structure still complied with the code of record for its original design, to characterize the likely impact of its failure on the stronger Building 707A, and to develop specific modifications that were necessary, technically feasible, and sufficient to provide a meaningful increment in the seismic capacity of Building 707 for input to the benefit/cost decision process.

New surface response spectra were developed for use in the structural evaluation of Buildings 707 and 707A based on the updated Site Seismic Hazard Curve. Rock outcrop motions for several return periods were convolved to the surface through lower bound, best estimate, and upper bound soil properties established during previous analyses for Building 371 in response to Defense Nuclear Facilities Safety Board Recommendation 94-3. The principal impacts of the hazard and response spectra update are: 1) the new hazard curves at a redefined rock elevation (-100 feet) result in rock PGA values well below those for prior earthquakes of comparable recurrence probability; 2) the changes in spectral shape and soil amplification result in surface PGA values that are below prior estimates at the same recurrence probability; but, 3) surface acceleration at the fundamental frequency of the modified Building 707A for PC-2 seismic demand is ~10% above the upgrade design level and for PC-3 seismic demand is ~50% above the upgrade design level.

The analysis first used simplified dynamic analyses to estimate demand-to-capacity ratios for limiting structural elements based on the 1000-year return period earthquake (PC-2). A fragility analysis was also performed by estimating the median fragility factor encompassing strength, ductility, and structural response margins. The limiting demand-to-capacity ratio was used to extrapolate to the seismic demand level at which collapse would occur with a 50% probability based on the uncertainty in building seismic capacity; this corresponded to a PGA at rock of 0.046g and a return period of 385 years. The collapse failure of Building 707 was further analyzed using a conservative scoping methodology to estimate the potential impact on the stronger adjacent Building 707A. A separate model of Building 707 was developed with the additional detail needed to establish and verify the scope of modifications that would
enable Building 707 to accommodate the limiting horizontal seismic loads. Several seismic analysts from Westinghouse Savannah River Company supported this seismic re-evaluation.

The new structural analyses establish a 385-year return period earthquake as the median collapse earthquake for Building 707. This value compares with the 555-year return period collapse earthquake used in prior facility safety analyses. This reduced capacity resulted from evaluation of the loads that must be carried by lightly welded connections between the precast concrete twin-tee wall panels that provide the main lateral force resisting system for Building 707. The expansion joint itself was at most a minor contributor to the vulnerability.

The adjacent, previously seismically hardened, Building 707A, was found to be more robust than had been thought and compliant with DOE requirements for such a hazardous facility. These requirements, designated as Performance Category 3 (PC-3), require structural integrity (confinement) for a 2000-year return period earthquake and collapse prevention for a 10,000-year earthquake. The analyses provide a second discovered vulnerability, however, when they conclude that failure of Building 707 is likely to cause partial failure of Building 707A. This interaction potential contributes significantly to the seismic risk during planned activities in the 707 Complex.

The increase in capacity that could be attained through a practical upgrade concept, which focused on accessible portions of the facility's lateral force resisting system, was estimated. The upgrades identified for Building 707 are estimated to change the median collapse earthquake to one with a 1700-year return period at a cost of $4M for the entire facility or $2M for the North half only (the portion adjacent to Building 707A). While the upgrades do not prevent interaction with Building 707A, they lessen its frequency of possible occurrence (from 1/385 to 1/1700 years). These upgrades which could be implemented at a cost of about $4M would increase the facility seismic capacity to about its previously concluded historical level (but not to current Performance Category 3 requirements) without physically interfering with the risk reduction activities in the facility. The proposed upgrades were constrained to not interfere with ongoing risk-reduction activities in the Building 707 Modules and were chosen to limit upgrade cost recognizing that larger expenditures would not be justifiable for the short remaining mission.

The upgrades developed in this study are not the upgrades that would be proposed to prepare Building 707 for a long remaining mission. For a longer mission, upgrades utilizing buttresses as in Building 707A would enable the facility to meet the PC-3 requirements which apply to a Hazard Category 2 nuclear facility and would provide significantly greater margin against collapse.

Nuclear Safety Impacts and Risks

The increased risk to the public and facility worker from this discovery was evaluated based on the best estimate of structural failure frequency and concluded to be an unreviewed safety question (USQ) due to the decrease in seismic return periods and an increase in consequences due to the interaction. Because of the positive USQ, a Justification for Continued Operation (JCO) was prepared and approved by DOE-RFFO with some additional technical directions. The JCO and approved documents established a plan of action focused on completing structural analyses required to support a decision on possible upgrades, preparing a white paper (Reference 4) to support a Kaiser-Hill recommendation on upgrading to DOE-RFFO, DOE-RFFO deciding whether to proceed with upgrades, and amending the safety basis in accordance with the decision and the rationale for it to close the USQ and JCO.
The updated risk studies focus on Site seismic risk since it has previously been shown to contribute more than 95% of the total Site risk to the surrounding public. Previous estimates of risk to the public had identified that the as-is condition of Building 707/707A dominates overall Site seismic risk. The new stabilization mission being implemented and the discovered vulnerability would increase the risk to the public further (currently estimated as ~44% of total Site seismic risk due to the discovered condition and material-at-risk increases to support the new stabilization mission). The discovered vulnerabilities cause total Site seismic risk to increase by almost 20% above the 1997 estimates for the peak closure case, more than offsetting other progress that has been made on risk reduction in the interim.

The consequences of seismic collapse are modeled using the Rocky Flats Cumulative Impacts Document methodology and current DOE Handbook 3010 recommendations for airborne release fractions and respirable fractions (Reference 6). Median weather assumptions are used to provide a “best estimate” of risk, and uncertainty in all assumptions is considered in the interpretation of results. Radiological consequences were estimated based on the MACCS2 code in terms of latent cancer fatalities within 50 miles of the site, and dose to a Maximum Offsite Individual at the Site boundary. Potential radiological doses (Committed Effective Dose Equivalent) to the Maximum Offsite Individual were estimated to be 4 rem, 11 rem, and 18 rem, respectively for Building 707 collapse, interaction causing additional partial collapse of Building 707A, and total collapse of both buildings. These estimates were combined with the seismic frequencies of occurrence to estimate a 707 Complex risk. Similar estimates were made for the population risk to over 2 million people within 50 miles of the Site. These estimates of risk were used to compare the 707 Complex to those from other Site nuclear facilities and to other nuclear industry risks.

To determine if this increased risk would be so high as to require mitigation regardless of cost or schedule impact, comparisons were made to other Site risks, to the Department of Energy SEN-35 Safety Goals, and to the historical risk perspective underlying restart of the facility in 1993. The risk to the public was determined to be well below the DOE SEN-35-91 Safety Goal for an individual’s chance of a latent cancer fatality (determined based on the population within 10 miles of the Site boundary), and to be only slightly higher than that determined for resumption of plutonium operations in 1993. Compliance with the Safety Goal, comparability of 707 Complex risk to that from other Site facilities contributing the other 56% of Site seismic risk, and the relatively modest (~20%) increase in total Site risk are concluded to demonstrate that the public risk increases, while clearly undesirable, are not intolerable.

Uncertainties in risk estimates were also evaluated. A study by ARES Corporation (Reference 8) initiated by the facility operating contractor, Safe Sites of Colorado, included the discovered vulnerability of Building 707, but did not include interaction with Building 707A (which was not determined at the time). The uncertainties modeled with probability distributions included the seismic hazard, the seismic capacity of each building, and the key release consequence parameters of weather, damage ratio, airborne release fraction and respirable fraction. This study estimated the risk as two-to-three orders of magnitude below the Safety Goal with 90% confidence.

Habitability of the structure for facility workers is a life safety issue that also needed to be addressed prior to initiating cost/benefit analyses. Habitability was concluded to meet minimum safety requirements when the code of record (1967) was determined to have been satisfied. Thus, the level of worker protection provided is comparable to many existing older facilities and, like the public risk, is undesirable but not intolerable.
Thus, the upgrade decision is concluded to be one that should be addressed from a benefit/cost perspective. The total upgrade of Building 707 (cost $4M) would lessen the 707 Complex share of Site seismic risk to ~17% and result in about a 20% reduction in Site seismic risk relative to the 1997 estimate for the peak closure case. The North half upgrade (cost $2M) has an intermediate impact (~26% Site seismic risk in the 707 Complex and an 11% reduction in total Site seismic risk relative to 1997).

Cost/Benefit Study

Cost/benefit studies were then performed to assess the identified practical upgrades. The studies used a model developed by the FEMA (Reference 9) to integrate the damage costs avoided for a complete range of discrete earthquake sizes over the remaining life of the facility. The earthquake sizes and the site-specific probability of an earthquake of each size are illustrated in Figure 2. The probabilistic or "expected" savings from the upgrade were then compared with the upgrade cost for a "base case" and a broad range of uncertainties involving impact magnitudes, upgrade structural benefit, and mission duration (remaining facility life).

Figure 2. Expected Annual Number of Earthquakes vs. Peak Ground Acceleration (% of g)

The damage model required inputs on degree of facility damage at each earthquake size and the corresponding magnitude of impacts on public and worker health, loss of equipment in addition to the structure, mission risks (loss of capability or substantial delays), and environmental risks. Based on the structural analyses performed for the existing and modified structure, fragility distributions were developed for the probability of structural failure (onset of building collapse) and its uncertainty. A
simple algorithm was developed using the FEMA model earthquake size thresholds and their intercepts with these distributions to estimate damage fractions for the range of credible earthquake sizes. These distributions were used to estimate the degree of facility damage.

The "costs" or potential impacts included in the model were: public safety (the risk of latent cancer fatalities); worker safety (injury or death); environmental impacts (added Site cleanup cost); mission impacts (cost to complete the facility's stabilization and packaging mission after the earthquake); and the D&D impacts (added facility cleanup cost). The other impacts were estimated using either default FEMA model inputs modified to reflect the impact of hazardous radiological material or available Site studies. Simple sensitivity studies were used to test the possible importance of estimated inputs. For example, two worker safety sensitivity studies looked at peak vs. average occupancy and a bounding assumption that all injuries were deaths. Results of the study for two proposed projects to upgrade a portion or all of Building 707 are shown in Table 1. Sensitivity study results are summarized in Table 2.

Table 1. Benefit/Cost Results for Base Cases Analyzed

<table>
<thead>
<tr>
<th></th>
<th>North Building</th>
<th>All of B 707</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefit/Cost</td>
<td>0.68</td>
<td>0.52</td>
</tr>
<tr>
<td>Cost</td>
<td>$2M</td>
<td>$4M</td>
</tr>
<tr>
<td>Total Benefit</td>
<td>$1.367M</td>
<td>$2.097M</td>
</tr>
<tr>
<td>Public Safety (%)</td>
<td>3.54%</td>
<td>3.04%</td>
</tr>
<tr>
<td>Worker Safety (%)</td>
<td>7.71%</td>
<td>10.03%</td>
</tr>
<tr>
<td>Environment (%)</td>
<td>54.08%</td>
<td>46.99%</td>
</tr>
<tr>
<td>Mission (%)</td>
<td>20.26%</td>
<td>22.56%</td>
</tr>
<tr>
<td>D &amp; D (%)</td>
<td>14.41%</td>
<td>17.38%</td>
</tr>
</tbody>
</table>

Based on the model, the proposed modifications are not cost effective (i.e., benefit/cost ratio less than one) given the remaining facility life for the base case conditions analyzed. The benefit/cost sensitivity studies favored the upgrades only for the most limiting uncertainty ranges. Further, they indicated the potential benefits of shortening the facility mission (e.g., accelerating residue stabilization with the use of the pipe overpack container) or removing some of the more hazardous material (e.g., relocating the plutonium metal and oxide stabilization activities to Building 371) in the event that upgrades were not adopted. Thus, Site managers, confronted with the choice of possibly diverting the resources necessary for upgrades from ongoing Site risk reduction activities just as the push toward Site closure was being mounted, had additional options to address risk and a documented basis to support their upgrade decision.
Table 2. Benefit/Cost Sensitivity Results

<table>
<thead>
<tr>
<th>CASE</th>
<th>Project Life</th>
<th>All of 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>0.68</td>
<td>0.52</td>
</tr>
<tr>
<td>2 Year Project Life vs. 4 in Base Case</td>
<td>0.36</td>
<td>0.28</td>
</tr>
<tr>
<td>6 Year Project Life vs. 4 in Base Case</td>
<td>0.36</td>
<td>0.74</td>
</tr>
<tr>
<td>Project Life Where Benefit/Cost = 1</td>
<td>6.3 yr.</td>
<td>8.9 yr.</td>
</tr>
<tr>
<td>Assume Fix at Same $2M Cost Prevents B707A Interaction</td>
<td>0.79</td>
<td>0.58</td>
</tr>
<tr>
<td>Assume Fix at Same $4M Cost Further Strengthens B707 One MMI Bin &amp; Prevents B707A Interaction</td>
<td>0.88</td>
<td>0.67</td>
</tr>
<tr>
<td>D&amp;D Costs Increase by $100M vs. $40M</td>
<td>0.82</td>
<td>0.66</td>
</tr>
<tr>
<td>Building at Peak Occupancy of 300 vs Time Average of 97</td>
<td>0.79</td>
<td>0.64</td>
</tr>
<tr>
<td>Building at Time Average Occupancy of 97 but All Injuries are Fatalities</td>
<td>0.82</td>
<td>0.66</td>
</tr>
<tr>
<td>Mission Impact Increase by $80M for D&amp;D in Building 371</td>
<td>0.94</td>
<td>0.74</td>
</tr>
<tr>
<td>Assume C-Line Rebar Missing and Repaired – No Cost Available</td>
<td>$317K Benefit</td>
<td>$472K Benefit</td>
</tr>
</tbody>
</table>

Conclusions

The analyses of structural capacity, facility risk, and benefit/cost confirm that the proposed upgrades do provide a meaningful increment in seismic capacity worthy of consideration for implementation if the facility mission is likely to extend to 2004 and beyond (although current plans are for completion in 2002). Conversely, a decision to emphasize alternatives currently being considered to shorten the facility mission with completion in ~2000 as part of the drive to close the Site by 2006, would make the upgrades not sufficiently cost-effective and therefore obviate further consideration. For the nominal mission to 2002, the upgrades are not calculated to be cost-effective, although the consequences of earthquake damage if a significant earthquake does occur are large.

There are three principal conclusions from the 707 Complex seismic evaluation and benefit/cost study (Reference 4):

1. The large difference between the modest expected annual adverse consequences and the large actual consequences in the event that the earthquake does occur could be cited as the basis for a
2. A decision to upgrade either the North half or even all of Building 707; while the benefit/cost results are below one, they are not so far below as to make a decision to upgrade an unreasonable one. A decision to upgrade can be viewed as a form of insurance whose value will be evident only if a significant earthquake occurs. Such a decision would weigh the impacts on Site workers and on the timing of Site closure, which would result from the damage caused by an earthquake that the upgraded building could survive, as sufficient to warrant the premium (the upgrade cost).

2. A decision not to upgrade is suggested by the preponderance of the analytical results presented and therefore should also be considered prudent. The consequences of structural failure, while clearly adverse, are not intolerable; the model attempts to objectively weigh the risk of unlikely actual damage against the certain cost of upgrades and finds the balance unfavorable for the upgrades.

3. The risk associated with a decision not to upgrade can be reduced by parallel decisions that minimize the mission duration in Buildings 707 and 707A; conversely, a decision to extend the mission of these buildings (e.g., acceptance of further delays in the plutonium stabilization and packaging line without a decision to relocate it) could tip the balance in favor of at least partial upgrades.

The study also provides additional insights regarding whichever decision would be made, and follow-on recommendations necessary to confirm critical assumptions on certain construction details and to install seismic instrumentation. The upgrades are clearly beneficial, if a significant earthquake occurs, but, such an earthquake has certainly not occurred in the last hundred years and is unlikely to occur in the next three to five years by which time the risk-reduction mission will be complete. Based on this study and other factors, DOE-RFFO decided to: (1) not upgrade the facility, (2) relocate the Plutonium Stabilization and Packaging System to Building 371, and (3) expedite the facility’s residue stabilization mission (e.g., adopted the pipe overpack container instead of extensive thermal stabilization and processing) to assure completion by 2002, and perhaps as early as 2000 for activities in the Building 707 Complex.

A key to the success of this model was the use of uncertainty studies to test the decision importance of model inputs that could not practically be rigorously derived. Had the uncertainties governed the cost benefit result, the decision makers could have elected to weigh them qualitatively or to seek better information.

References


