Nuclear Criticality Safety Engineering Training
Module 12[1]

PREPARATION OF NUCLEAR CRITICALITY SAFETY EVALUATIONS

LESSON OBJECTIVE:

> To introduce the elements of a nuclear criticality safety evaluation (NCSE) and the underlying thought processes that contribute to the development of a good NCSE.

1.0 INTRODUCTION

This module is intended to help the inexperienced criticality safety professional (CSP) understand the thought processes that go into preparing a nuclear criticality safety evaluation (NCSE), and perhaps remind the experienced person about the principles that have become automatic over time. While the format and content of the NCSE are often given in Standards or Guides, little is said about the underlying approach and the target objectives used to develop a good NCSE. This module is an attempt to fill that gap, and might be subtitled *The Philosophy of Preparing NCSEs*. The approach taken in this module might be compared to that of a primer. The module makes extensive use of an example NCSE that might have been written for a hypothetical facility. As you read each section of this NCSET module, refer to the sections of the sample NCSE that is included in its entirely following the module.

2.0 WHAT IS A GOOD CRITICALITY SAFETY EVALUATION?

The ultimate product of a criticality safety evaluation is a document that prescribes the criticality safety controls and limits for an operation with fissionable material such that the operation is subcritical under all normal and credible abnormal conditions. As stated in ANSI/ANS-8.1-1998, Section 4.1.2,

> "Before a new operation with fissionable material is begun, or before an existing operation with fissile material is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions."

A good NCSE takes the reader through the analysis that supports the above requirement and leads them to the limits and controls required for safe operation, explains the basis for all assumptions and conclusions and supports the conclusions with appropriate validated calculations or references. A good NCSE is written with sufficient level of detail, clarity and lack of ambiguity that an independent CSP familiar with the process can understand it and judge the results.

DOE contractors have a DOE-approved criticality safety program description document that addresses the approach used by the contractor to satisfy requirements of the ANSI/ANS-8 standards, such as the Section 4.1.2 above, and DOE orders. Also, the contractor likely has more

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detailed site/facility procedures that specify requirements for individual NCSEs. A good NCSE meshes with site procedures to ensure applicable requirements and site expectations are met.

3.0 BASIC STEPS IN THE DEVELOPMENT OF A NCSE

Any group of CSPs would undoubtedly disagree when asked to list the steps to follow in the development of a NCSE. However, the following objectives should be met by any approach used to develop a NCSE.

1. Know the system/facility being analyzed.
   → Thorough and accurate knowledge is a prerequisite to a good analysis.
2. Identify potential criticality accident scenarios.
   → This can be done using formal methods (e.g., What-If analysis, Hazard and Operability Analysis (HAZOP), failure modes and effects analysis) or by using engineering judgment based on operating experience, incident data and interviews with operations personnel. Adherence to the double contingency principle should be demonstrated except in rare circumstances such as shielded facilities.
3. Eliminate potential accident scenarios whenever practical.
   → Modify the facility, equipment or processes to eliminate initiating events to the extent practical.
4. Use the preferred hierarchy of criticality safety controls.
   → The preferred order of controls is: passive engineered controls, active engineered controls, administrative controls. Ensure that the complete control set is achievable and fits within the total safety program.
5. Document the technical basis for nuclear criticality safety.
   → Documentation should include the analyses that show compliance with ANSI/ANS-8.1 Section 4.1.2 (i.e., that the entire process will be subcritical under both normal and credible abnormal conditions), and the derivation of controls and limits.

The following list is a reasonable set of steps that meets the above objectives, but others could serve as well, provided the final product contains the same information as the one developed according to this outline.

1. Familiarization with operations and the facility
2. Description of methodology
3. Identification of the scope of normal operations
4. Identification of contingencies that could affect NCS
5. Analysis of normal operations and contingencies
6. Derivation of controls and operating limits
7. Preparation of the NCSE document

These steps are not independent and often overlap as the NCSE is being developed. For example, analysis of normal operations and contingencies usually is done at the same time. Development of limits is a part of the analysis. Although some people might approach the

NCSE elements in a different order, Step 1 must always be done first. As each step in the NCSE process is discussed, the sample NCSE will be used to demonstrate that step.

3.1 ***Familiarization with Operations and the Facility***

The CSP must understand the operations that will be analyzed in the NCSE, but very often the novice will rely on operations personnel to describe the key points of the operations. Many times the CSP will rely on the same operations people to identify potential abnormal and accident conditions. This can be a good starting point, but the CSP must have a first-hand understanding of the facility, operations and processes, do his/her own analysis, and then discuss the results with operations personnel. Ongoing interactions with the operations staff and the operators are a necessary part of performing an NCSE. Understanding of the operator and supervisor knowledge, training process, procedure use and level of Conduct of Operations employed at the facility is also needed to determine the level of administrative control implementation. Other human factors issues also need to be understood to judge the frequency of failure of administrative controls that may be placed on the operation. For example, an administrative control that prevents drums from being stacked is less likely to be violated if drums are not stacked anywhere in the facility compared to if some drums types are stacked and some are not.

How does one go about learning this background information? In today's safety climate, every process and operation requires safety reviews, system design descriptions, design drawings, operating procedures, etc. Every non-reactor nuclear facility has some form of an approved Safety Analysis Report (SAR) or Documented Safety Analysis (DSA). The SAR provides basic information about the facility including dimensions, proximity of the other laboratories, utilities entering the laboratory, etc. It also discusses hazards in other parts of the building that could impact operations in the subject area. Combined with the educational and background training of the CSP, much of the information needed to start the process can be extracted from these documents.

Most, if not all, operations have procedures associated with them and new experiments usually have review packages that have been approved by safety committees. Experiment plans generally provide technical drawings, lists of connections to utilities and enough information to supplement the safety basis documents as a starting point for discussions during the facility walk-through. Read and understand all the background material that can be found.

The next step in understanding the operations and the facility should be a walk-through with scientific staff, operators and technicians. This interaction lets the CSP visually see the layout of the facility and ask detailed questions about the equipment and operations. Ask questions of the operations staff, facility staff and the operators who are the first line of safety when handling fissionable materials. These people can provide insights into problem areas, potential accidents and operating conditions that the CSP may not notice. It usually takes more than one visit to understand the process and equipment well enough to develop the NCSE.

Sometimes an overlooked point is the rest of the facility in which the operation is taking place. The CSP should understand how this operation interacts, or could interact, with other operations in the facility or nearby facilities. Similarly, operations in nearby facilities should be examined for potential impacts on the subject operation.

It is extremely important that the CSP preparing the NCSE understand all aspects of the operation being analyzed and the interfaces with utilities and other fissile material operations performed in the facility. At times this might require consulting experts in other fields, such as chemistry, when process changes could result in potential criticality safety problems, such as solids precipitating from solutions. The NCSE should describe all of the operations within the scope of the analysis along with the interfaces with other processes and utilities. A schematic can be very helpful to illustrate the boundaries of the process being analyzed in the NCSE as well as interfaces with other processes and utilities, such as process water, plant air, ventilation, etc.

Read Sections 1 and 2 of the Sample NCSE

3.2 Description of Methodology

It is generally best to start with simple analysis techniques, such as handbook values, and work up to detailed calculational models if needed. In the attached example NCSE, the KENO-Va code is used, but any validated code is acceptable.

When codes are used to derive limits and controls, they must be *validated*. The purpose of problem-specific code validation is to ensure that the code, cross sections and approach being used are applicable to the system being analyzed. Generally this is accomplished by using the selected code and cross sections to calculate benchmark problems having the same or similar materials and characteristics as the system being analyzed. If no such benchmark cases exist, the existing cases may be interpolated or extrapolated to that system. Extrapolation must be done with care and be guided by the experienced criticality safety expert. The TSUNAMI code in the SCALE package is an example of a tool available to aid in determining the applicability of benchmark problems and providing a quantitative estimate of the suitability of benchmark problems to validate the system being analyzed. Additional validation requirements are given in ANSI/ANS-8.24.

Read Sections 3 and 4 of the Sample NCSE

3.3 Identification of Contingencies

During the facility walk-through, the CSP should always be thinking about potential criticality safety problems. All of the factors that affect reactivity should always be kept in mind when looking at the facility. For example, are there external sources of unwanted moderators or reflectors? Are there geometrically unfavorable containers or equipment present where materials could inadvertently accumulate? The CSP should be looking for conditions that could occur during normal operations and also off-normal situations such as fire sprinkler activation, water pipe breaks, etc.

DOE-STD-3007-2007 states that a disciplined methodology should be used to identify contingencies. Examples of acceptable methods are What If, Qualitative Event or Fault Trees, Probabilistic Risk Assessments, HAZOP and Failure Methods and Effects Analysis. The What-If Checklist and HAZOP methods, two of the most common approaches, are described in detail here.

The What-If analysis with the associated checklist is a systematic technique for identification of process upset conditions using a multidisciplinary brainstorming approach. The checklist is a list of sample questions covering variations in process parameters and/or variations in parameters important to criticality safety. Sample checklist questions include:

- What if the fissile mass limit is exceeded?
- What it the solution/water level is too low?
- What if a change in the H/X ratio occurs?

A session is held to perform the What-If analysis with a team of personnel from operations, criticality safety and other disciplines who can provide insight into the process upsets. A graded approach can be used to determine the size of the team depending on the complexity of the operations being evaluated. First, the physical and process boundaries of the system being analyzed are defined and the system is divided into process zones. Then the activities and processes that occur in each of the defined process zones are discussed by the process expert to familiarize all participants. The team leader of the session begins by asking, "What if something goes wrong?" and the participants contribute ideas, such as "What if the wrong material is shipped?" The leader ensures questions are heard and captured, prompts for input from subject matter experts, and focuses the discussion to ensure a comprehensive and rigorous analysis. The team leader will also direct discussion of causes and consequences of each scenario, the measures protecting against each scenario and other relevant information to complete the What-If analysis. Questions that cannot be answered by the group are documented for further investigation. Before moving to the next process zone, the team leader reads through the checklist to prompt the group for additional scenarios and ensure that a comprehensive and robust analysis of upset conditions has been completed.

A team member documents the scenarios discussed in the What-If hazards identification table regardless of the impact the scenario has on criticality safety. Completed tables will form the basis for the analysis which includes event screening and scenario development. A What-If hazards identification table with a few example scenarios identified for a process zone involving receipt of shipping containers is shown in Table 1.

Using the What-If hazards identification table, the CSP screens the hazards to determine if they are a) credible and b) have an impact on criticality safety. The preventive measures identified along with the CSP's knowledge of the configuration needed to support criticality for the system being analyzed are used in the screening process. If the scenario is clearly not credible or does not impact criticality safety, that decision is documented and justified in the What-If screening results table and no further analysis is performed. If the scenario cannot be easily dismissed, the scenario carries forward into the contingency analysis section of the NCSE. An example What-If screening results table using the scenarios identified in Table 1 is shown in Table 2. Table 2 is generally included in the NCSE as an appendix. One advantage of including it is that the events screened out as not credible or having no impact are listed for reviewers to confirm that they were considered. Also, scenarios that are clearly subcritical (e.g., contain less than the single parameter minimum subcritical mass) can be justified as subcritical in the table without developing a full contingency evaluation in the NCSE.

The HAZOP method is also a multidisciplinary brainstorming approach. A team reviews the operation to determine if deviations from its design intent lead to undesirable consequences.

Table 1. Example What-If Hazards Identification Table

Process Zone 1: Shipping Container Receipt					
No.	What-If	Causes	Consequences	Preventive Measures	Comments
1.1	What if certified shipping container is received damaged?	• Truck damage during transportation • Damaged container sent by shipper	• Structural damage • Damaged shipping container • Damage to fissile material in package	• Receipt inspection • Driver qualification • Shipper's quality assurance program	
1.2	What if truck impacts building or dock?	• Driver error • Brake failure • Weather	• Structural damage • Damaged shipping container • Damage to fissile material in package • Personnel injury	• Robust shipping container • Driver qualification • Site speed limit	Truck backs up to dock to unload
1.3	What if load contains more containers than expected?	• Shipper error	• Maximum allowed Criticality Safety Index (CSI) for the shipment may be violated	• Shipper's quality assurance program	

Table 2. Example What-If Hazards Screening Results Table

Process Zone 1: Shipping Container Receipt						
No.	What-If	Causes	Consequences	Screening Results	Justification	Carries Forward?
1.1	What if certified shipping container is received damaged?	• Truck damage during transportation • Damaged container sent by shipper	• Structural damage • Damaged shipping container • Damage to fissile material in package	Insufficient mass involved to support criticality	The 1 shipping container involved contains less than the minimum subcritical mass of fissile material	No
1.2	What if truck impacts building or dock?	• Driver error • Brake failure • Weather	• Structural damage • Damaged shipping container • Damage to fissile material in package • Personnel injury	Unmitigated scenario is not credible to result in criticality	Damage to certified shipping containers would be minimal due to backing speed	No
1.3	What if load contains more containers than expected?	• Shipper error	• Allowed Criticality Safety Index (CSI) may be violated	Infinite array of this shipping container is not subcritical		Yes

HAZOP requires detailed design and operating information including accurate process drawings and possibly operating procedures. The team leader guides the team through the process design using guide words, such as low, high, no, more, less, etc, combined with process parameters, such as temperature, concentration, flow, power, moisture, etc. For example, the guide word "high" combined with the process parameter "temperature" results in the deviation "high temperature." The team then determines what, if anything, could cause this deviation, the consequences of the deviation and the applicable preventive measures. Using an example of high temperature related to an evaporator process, a cause could be "failure of cooling water pump", a consequence could be "evaporator overheats" and a preventive measure could be a "high temperature cutoff shuts down the heat source."

The What If checklist questions and the HAZOP can be tailored to focus the discussions on scenarios that affect NCS parameters. A graded approach can be taken based on the complexity of the operation being analyzed. Certainly a HAZOP would not be needed for an operation that only involved storage of closed fissile material containers. On the other hand, HAZOP may be very helpful for a complex solution process with many inputs. The experience at the facility performing and analyzing that type of operation should also be considered when determining the hazard identification methodology to be used. For example, an evaluation of a new glove box operation handling plutonium metal at a facility that has ten NCSEs for other similar glove box operations for handling plutonium metal may not require a formal hazard identification session. However, the addition of a solution processing system to such a facility would warrant a formal hazard identification session.

Following the hazards analysis the CSP should have a reasonably good idea of the number and normal range of operating parameters that are important to criticality safety. Now the task is to determine what departures from normal operations could lead to a contingency situation. For example:

- Is it credible to increase reflection beyond that assumed in the analysis?
- Can enough moderator be introduced to cause a problem?
- What happens if the mass limit for a glove box is exceeded by a reasonable amount?

Basically, the question is what happens if any controlled parameter limit is violated and what can you do to minimize the probability that a violation will occur. Often the contingency analysis will result in changes to the normal operating parameters for either the facility or a process, causing the contingency analysis to be repeated.

3.4. <u>Analysis of Normal Operations and Contingencies</u>

While experiment plans and system design descriptions are good sources of what the normal operations are expected to encompass, it is always necessary to talk to the operators or experimenters. Most of the times these people will want to use as much material as possible in many different ways, and often they have a different interpretation of what limits the safety documents actually impose. It is up to the CSP to reconcile what the operators or experimenters want to do with what is safe. Normally, some of the contingency analysis is done at the same time that normal operations are analyzed, since operational limits will sometimes have to be modified based on the contingency analysis results. Every NCSE must cover all of the operations within the scope of the evaluation and credible contingency scenarios taking into account all materials and configurations that are expected to be present.

Unless a strong case can be made for not adhering to it (e.g., in shielded facilities), the double contingency principle should always be followed during the analyses. As stated in ANSI/ANS-8.1-1998, Section 4.2.2,

> "Process designs should incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible."

Calculations are needed when standard references and handbooks do not address either the materials or configurations that are expected in the operation for which the NCSE is being prepared. This raises the complexity of the NCSE since the calculational method must be validated. Also, derivation of inputs into the computer code, such as dimensions and material number densities, need to be explained, which may require pictures or sketches. Similarly, output from the code needs to be presented in an understandable manner, which generally entails tables or graphs. In the sample NCSE, the analysis begins with determining the most reactive solution concentration, container loadings, etc. and then goes on to analyze the specific operations and upsets.

Read Section 5 and Appendix A of the Sample NCSE

The sample NCSE evaluates normal operations and contingency situations in two separate sections of the document. Some CSPs prefer to evaluate them at the same time. Either approach can work as long as all situations are analyzed.

3.5 Controls and Operating Limits

The NCSE should include a concise summary of all limits and controls that have been derived from the evaluation. While the NCSE might include references to good practices or defense in depth measures, the controls should reflect only the administrative rules, equipment or systems that are required to maintain the margins to criticality as analyzed in the NCSE, or to ensure that operations are consistent with the assumptions made in the analyses. The CSP should ensure that assumptions important to operations are not hidden within the document but are clearly identified in the controls section. Although the description section must be understood by operations personnel as it describes the operations that have been evaluated for criticality safety, important operating parameters, controls and assumptions hidden in the analysis without being clearly stated as limits and controls can result in shutdown of operations and/or audit findings.

The analyst should hold discussions with operations staff throughout the NCSE development process to obtain their concurrence with the controls and limits. Controls proposed by the analyst may conflict with requirements imposed on the operation by other disciplines and/or their experience may lead to a better control scheme. Determination that the controls cannot be implemented in the facility after the NCSE is written and peer reviewed will result in significant additional work and associated costs.

Other site programs and requirements should also be considered when writing NCS controls. The robustness of Conduct of Operations, Configuration Management, and other programs at the site is a factor in how the controls are implemented. For example, inspection criteria for passive design features may need to be stated in the NCSE unless the Configuration Management program has an element for assessing degradation of such components. Also, NCS controls need to be robust to ensure that the upset conditions evaluated as contingencies are indeed unlikely. This determination often requires knowledge of the NCS program within the facility. For example, if drums are not allowed to be stacked anywhere in the facility, the upset of an operator stacking drums is more unlikely, due to the consistently applied limit and its reinforcement in training, than if drums are stacked in one process but not in another in the same facility. Where administrative controls are complicated or inconsistent, the CSP should consider whether independent verification of control compliance is needed, and if required, explicitly state it in the control.

Read Section 6 of the Sample NCSE

3.6 The NCSE Document

The NCSE document is the product that conveys the results of the criticality safety evaluation to many different types of readers. Each NCSE is peer reviewed by a qualified CSP that is independent of the CSP who performed the evaluation. It should clearly state any assumptions that were made about the presence of criticality control equipment or systems so that safety analysis personnel can evaluate the need for changes or additions to the authorization basis documents. A sampling of the computer code inputs used in the analysis should be included. However, even with the required details in the document, the NCSE must be understandable to high level reviewers, including regulatory oversight groups.

The NCSE is then generally reviewed and approved by operations personnel who accept the controls and limits of the NCSE. The NCSE may also need to be accepted by a site or facility safety board. Additional levels of review and approval are often necessary but vary according to the requirements of specific sites.

The attached NCSE is an analysis of a generic beaker leaching operation and represents a general approach that can be used for most analyses. A key point for the CSP to remember is that not all NCSEs are identical, and that a graded approach is necessary based on the materials and hazards at specific facilities as well as the complexity of the operation being analyzed. Note that while many traditional NCSEs (such as the attached example) focus on demonstrating that the double contingency recommendation is met, other NCSEs may instead seek to demonstrate that a criticality accident is not physically possible, or is so unlikely as to not be credible.

1.0 INTRODUCTION

The primary purpose of this evaluation is to provide and document the technical basis for criticality safety of the Beaker Leaching (BL) process.

2.0 DESCRIPTION

The BL process is used to dissolve solid forms of highly enriched uranium in nitric acid to produce uranyl nitrate solution. Demineralized water is also available in the hoods. A detailed description of the BL process is provided in the controlled process description document [1]. Details of the equipment are included on the BL process identification and detail drawings.

The solid forms of uranium dissolved in 30% nitric acid are:

a) uranium metal chips, turnings, fines, sludge, scrap, and clinkers,
b) U_3O_8 or UO_3,
c) roughing filters from BL hoods, and
d) contaminated combustibles.

2.1 Fixed Equipment

The BL equipment layout is shown in Figure 1. The process is performed in two fume hoods (hoods A and B) located on the east wall of Room X. Each hood has three work stations that are separated by 7.375 in. wide (minimum) dividers. Each hood is supplied with at least one demineralized water and one nitric acid supply line and is required to have drain holes. Wet vacuum is supplied to the hoods through a 24 in. tall, 4 in. nominal diameter glass wet vacuum trap that is equipped with a visible and audible overflow alarm. Leachate is transferred to one of two 6-in. nominal diameter by 36 in. tall cylindrical leachate columns located at the end of the hoods or to a safe bottle. Process exhaust ports located in the rear and top of the hoods and covered by roughing filters exhaust air to Stack 99 (S99). Each hood contains one continuous shelf located in the back of the hood for pans. The shelf's surface is approximately 10 in. wide and a minimum of 23.5 in. above the hood floor. Room X is located within a large geometry exclusion area meaning containers and equipment with an internal volume greater than 4 L are not allowed unless they are specifically analyzed, positioned or sealed to prevent the introduction of fissile solutions, or equipped with drainage features to prevent an unsafe depth of liquid from accumulating.

2.2 Beaker Leaching Process

A single feed unit (can, bag, or filters) is first brought to the dissolution workstation. The dissolution workstation equipment consists of a 4-L dissolver beaker, stainless steel stirrer or spatula, a hot plate for uranium dissolution, and a 4-L "clean" beaker containing 30% nitric acid and/or demineralized water. The uranium-bearing material to be dissolved is slowly fed from a feed unit to a warmed 4-L dissolver beaker on a hot plate filled with liquid from the 4-L "clean" beaker. Uranium-bearing material is added until dissolution is complete and the solution is saturated. The material from the feed unit may be dumped into a pan to sort through feed material prior to dissolution and then the material may be returned to the feed unit.

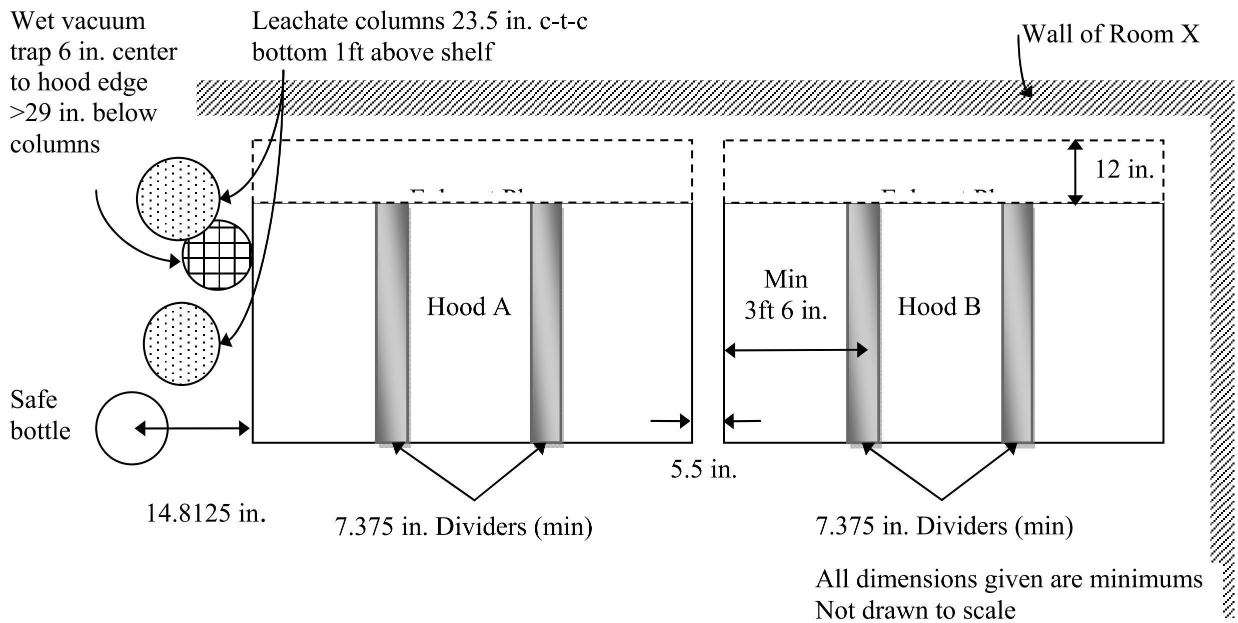

Figure 1. Schematic of Beaker Leaching Hood Layout

Next the 4-L dissolver beaker is taken to a filtering workstation. A filtering workstation may be set up in any of the three workstations in the hood and will most likely be adjacent to the dissolution workstation, separated by a minimum 7.375-in. wide metal divider. Here the solution is filtered through a 1.86-L Buchner funnel lined with filter media into a 4-L Erlenmeyer flask. The wet vacuum system may be used to transfer the solution from the beaker to the flask. The solution transfer may be followed with a water rinse of the Buchner funnel. The leachate (filtrate) collected in the 4-L Erlenmeyer flask is either manually poured into one of the safe bottles located against the hoods or is vacuum transferred to one of two leachate columns. The leachate columns are eventually drained to safe bottles. One safe bottle may be positioned against each of the hoods, A and B, in addition to the safe bottle that may be staged at the end of hood A as shown in Figure 1. The solids collected on the filter media, other than metal pieces that are returned to the dissolution beaker for further dissolution on subsequent passes, are placed in a pan. Pans may remain in the hood on elevated shelves until they are transferred out of the process.

The BL process also includes sampling of the safe bottles brought to the hoods. Solution from each safe bottle is transferred directly to a sample bottle using a pipette or is transferred to a beaker and then poured into a sample bottle. The sample bottle is sent to the laboratory or placed in storage.

To process contaminated combustibles, a clean 4-L beaker of nitric acid and water is prepared in the dissolution workstation and the combustibles are dipped into the beaker. Combustibles include materials brought into the process in plastic bags, roughing filters from the BL hoods, and wipes used to clean the plastic bags or the hoods. The wet combustibles are laid out to dry on the dividers, pipes in the back of the hoods, or hood floor. Once dried, the combustibles are placed in a plastic bag, hand-carried out of the process, and placed in a combustible collector or combustible drum. The 4-L beaker of uranium solution is taken to the filtration workstation and filtered, following the process described above. The filtered solution may be transferred from the 4-L Erlenmeyer flask to a 4-L beaker and returned to the dissolution workstation for concentration on the hot plate. After concentration, the solution is returned to the filtration workstation in a 4-L beaker and/or placed in sample bottles following the process described above.

2.3 __Process Boundaries__

A simplistic representation of the BL process showing the process boundaries is given in Figure 2.

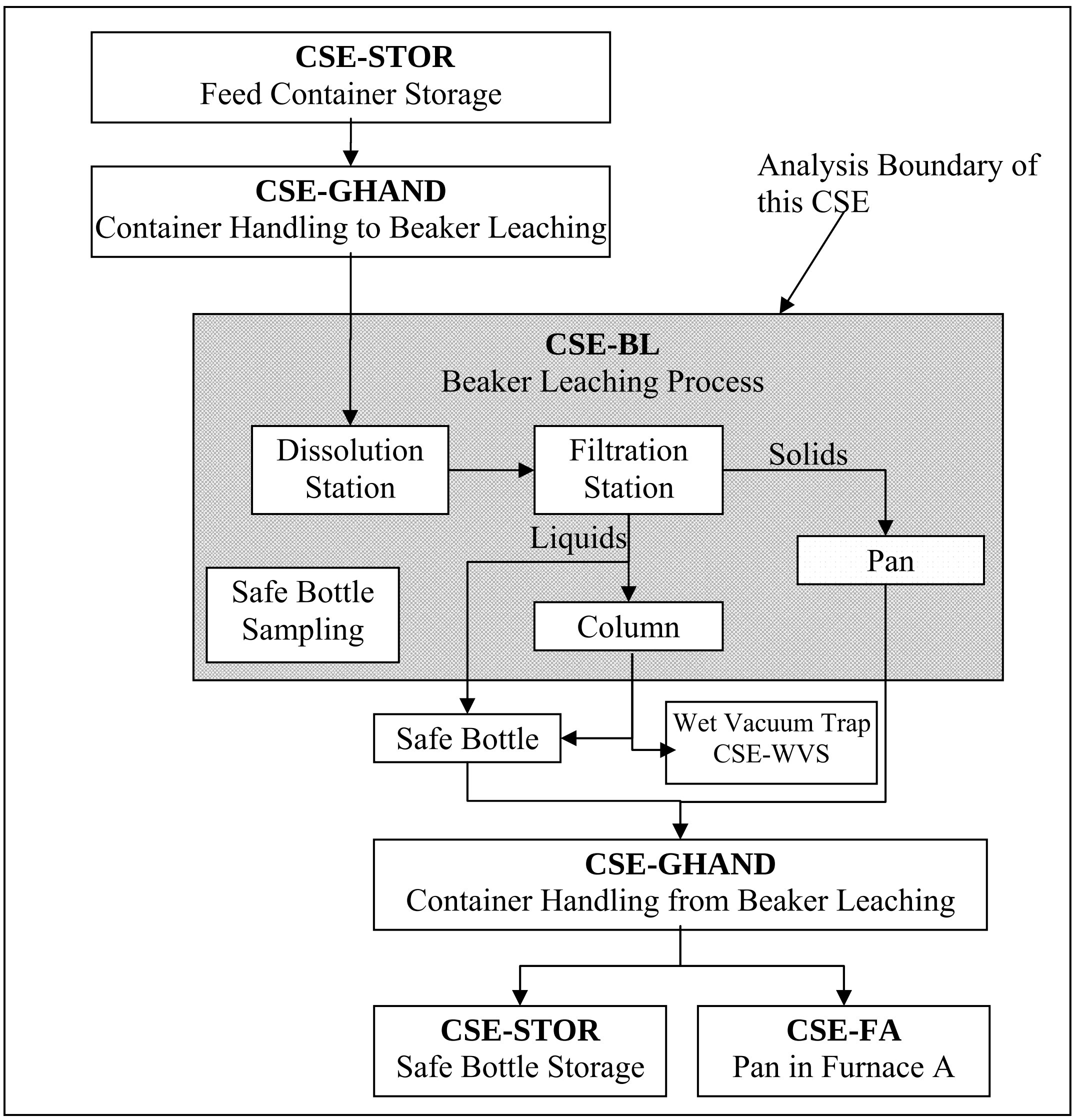

Figure 2. Simplistic Material Flow and Analysis Boundary for Beaker Leaching

2.3.1 Material Input

Because of the wide range of feed materials that can be processed through the BL process, the number of processes in which the feed material can originate is quite large. The feed unit is brought to the Room X BL area using the general handling guidelines found in CSE-GHAND. The allowed feed units are:

- A hospital can or green salt can loaded with up to 20 kg net weight UO_3 or U_3O_8, OR
- A hospital can loaded with up to 5 kg net weight dry U metal or 3 kg net weight wet U metal as U metal chips, turnings, and fines, OR
- A modified hospital can loaded with up to 10 kgU as U metal chips, turnings, fines, sludge, scrap, and clinkers, OR
- A large or small plastic bag of combustibles with up to 350 g-^{235}U, OR
- Roughing filters from a BL hood.

The BL roughing filters are located in the back or top of the BL hoods and are removed into the hoods for cleaning. The boundary for feed material entering into the BL process is the hood opening.

2.3.2 Material Output

Uranium solution is removed from the hoods by transfer to the wet vacuum system, leachate columns, or safe bottle positioned near the BL hoods. The safe bottle is taken to and from the hood using the general handling guidelines found in CSE-GHAND. The bulk of the uranium solution passes out of the BL process when transferred into a safe bottle or the wet vacuum trap. The wet vacuum system is evaluated in CSE-WVS.

Small quantities of uranium are present in the filter media of the 1.86-L Buchner funnel as undissolved solids. These solids are placed in pans that exit the process boundary when removed from the hood. All pans are sent to Furnace A. Leached combustibles left to dry in the hoods are removed from the process when removed from the hood and placed in a contaminated combustible collector per CSE-STOR.

There is also the potential for uranium in the hood exhaust systems. The roughing filters pass out of the system after they are sent through the BL process, leached and transferred out of the hood for disposal. The exhaust travels beyond the hood filters through exhaust ductwork to Stack 99. The exhaust exits the BL process at the point where the ductwork reaches the first floor of Room X.

3.0 UNIQUE OR SPECIAL REQUIREMENTS

There are no unique or special requirements for this NCSE.

4.0 METHODOLOGY AND VALIDATION

The analysis in subsequent sections uses several methods. First, subcritical limits from standards and handbooks, including ANSI/ANS-8.1 and TID-7016, are used. BL operations are also compared to a critical experiment. However, because the critical experiment is unreflected, computer code calculations are also performed using KENO-V.a.

Calculations were performed using SCALE 5 KENO-V.a [2] with the 238-group ENDF/B-VI cross section library. The calculations were run with the CSAS25 analytical sequence on a Hewlett Packard Series ZZZ workstation which is maintained under configuration control by the Nuclear Criticality Safety Group. The inputs and outputs are archived in directory xxx/cse-bl on the workstation. KENO-V.a has been validated by modeling over 500 critical benchmark experiments with the code [3] using the process outlined in Figure 3. The experiments modeled included high enriched U metal, oxides, uranyl nitrate and uranyl fluoride solutions over a range of moderation levels, enveloping both fast and thermal energy systems. The experiment fissile geometries included spheres, cylinders and slabs and both bare and water reflected configurations were evaluated. The steel or aluminum structures of the experimental apparatus were also modeled in the benchmark evaluations. These fissile materials, enrichments, moderation levels, geometries, and reflecting materials are evaluated in the calculations in this evaluation indicating that the calculations fall within the range of applicability of the validation. Thus the Upper Subcritical Limit (USL) determined in the validation of 0.957, which includes an administrative margin of 0.02, is acceptable. Because the benchmark suite includes many experiments that are very similar to the modeled configuration, an administrative margin of 0.02, which has been deemed acceptable for well validated systems at the site, is acceptable. Calculated $k_{eff} + 2\sigma$ values that are less than the USL are subcritical.

5.0 PROCESS ANALYSIS

5.1 <u>Parameters</u>

5.1.1 Mass

Uranium mass is controlled for the dissolving and filtering operations by limiting the amount of feed material that can enter the process; each dissolution workstation is limited to one feed unit. The feed unit contents were discussed in Section 2.3.1. The overall uranium mass in the hood is not controlled because the uranium mass in the pans on the shelf is unquantifiable.

The uranium mass in a feed unit is limited by the nuclear criticality safety requirements on the operation that generated that unit, not the BL process (with the exception of the BL roughing filters). CSE-CONT also imposes loading limits for feed units transported to the process. All approved feed units have been demonstrated to be subcritical when fully water-reflected in CSE-CONT.

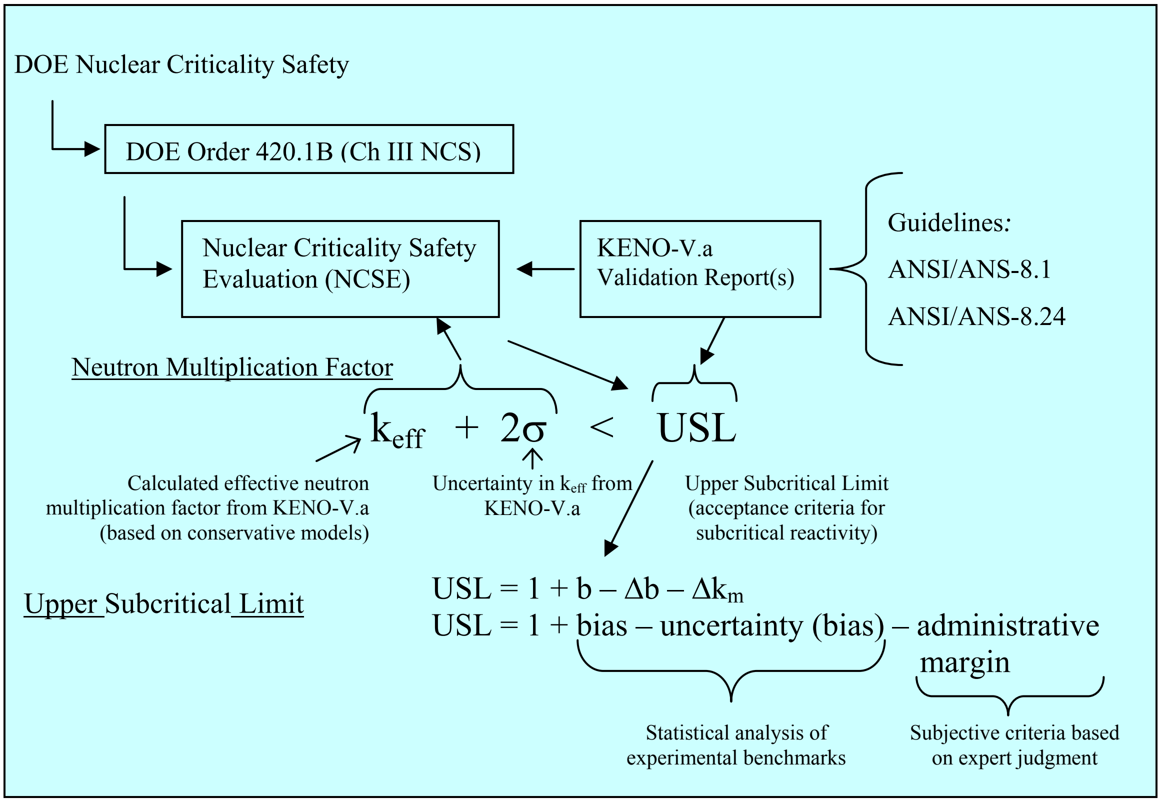

Figure 3. Flowchart for use of USL with Monte Carlo Calculations

5.1.2 Geometry

Geometry is controlled in the BL process. In addition to common process containers that are controlled by CSE-CONT, the geometry of other process-specific pieces of equipment is controlled. The geometrically favorable pieces of equipment include: hoods that have drain holes limiting solution depth to 3 in., wet vacuum traps that are no more than 4.625 in. in outer diameter, and hood exhaust filters that have bottom heights no less than 9.5 in. above the floor of the hood. The leachate columns have also been shown to remain subcritical based on geometry. An additional geometry control requires plastic bags to have corner slits to minimize potential accumulation of uranium solution.

5.1.3 Interaction

Interaction is controlled in the BL process. The hoods are equipped with dividers that passively provide a minimum of 7.375 in. spacing between adjacent workstations; however, solution can pass under the dividers in the event of a spill or process upset. The minimum spacing between workstations in adjacent hoods is 5.5 in. Interaction between containers in a single workstation is not controlled. Spacing is provided between the stored pans and process containers by the height of the pan shelves above the hood floor. The leachate columns are installed with 23.5-in. center-to-center (c-t-c) spacing and the top of the wet vacuum trap is greater than 29 in. below the leachate columns. The c-t-c spacing between the wet vacuum trap and the safe bottle area is greater than 20 in. One safe bottle may also be brought to each hood and placed in the fixed position holder with no additional spacing requirements. No other fixed uranium bearing equipment is located within 4 ft of the BL hoods.

5.1.4 Volume

Volume is controlled in the BL process. The dissolution workstation is limited to one feed unit, one 4-L dissolver beaker, one 4-L “clean” beaker for 30% nitric acid or water, and one pan for sorting feed materials on the hood floor (additional pans may be on the shelf).

The filtration workstation is limited to the 4-L dissolver beaker that is brought over from the dissolution workstation, one 1.86-L Buchner funnel/filter combination, one 4-L Erlenmeyer flask, one non-shelved pan for the collection of filtered solids, and one sample bottle. The feed unit is not permitted at the filtration workstation.

5.1.5 Concentration/Density

The concentration of uranium in solution and the density of solid forms of uranium are not controlled. Uranium solutions are modeled at optimum concentration as confirmed by KENO-V.a calculations and dry forms of uranium are evaluated at maximum credible densities.

5.1.6 Neutron Absorption/Poison

Absorption is not controlled. The process only contains materials that act as mild poisons for moderated systems and these poisons are not credited. Note that the hood stainless steel floor is explicitly modeled. In this case modeling the floor is more reactive than modeling nothing below the containers.

5.1.7 Moderation

Moderation is controlled for some feed cans loadings per CSE-CONT but is not controlled in the hoods. The feed can is considered to be properly loaded under normal conditions. The degree of moderation is not controlled for feed added to the dissolver beaker. The uranyl nitrate produced from dissolution and collected in the dissolver beaker, 1.86-L Buchner funnel/filter combination, 4-L Erlenmeyer flask, wet vacuum traps, leachate columns, sample bottles, and safe bottles are modeled at optimum concentration (see Section 5.1.5). Pans are conservatively modeled as filled with optimum concentration solution although the contents are either dry such as during feed sorting, or dry out over time, such as filtered solids from the Buchner funnel.

5.1.8 Enrichment

The enrichment of uranium materials processed and handled within the BL process is not controlled. For the purposes of this evaluation, the uranium within the process is no more than 97.7 wt% enriched in ^{235}U due to the upper limit of material available at the site. KENO-V.a calculations were performed with 100% ^{235}U. Critical experiments and some handbook data were used to evaluate 93.2 wt% enriched U. The difference between the subcritical limits for 93.2 wt% and 97.7 wt% is minimal.

5.1.9 Reflection

Reflection is limited for the purposes of nuclear criticality safety due to the location of process equipment used within the BL hoods but is not controlled. The hoods are located 27.125 ± 0.25 inches above the room floor limiting reflection from the concrete floor. The hoods are located near concrete walls, but the thickness of the exhaust plenums in the back of the hoods places the workstations at least 12 inches away from the rear wall. Hood B is also located more than 12 inches from the side wall. The hood walls and floor are constructed of thin stainless steel (i.e., ≤ 0.1875-inch thick).

During normal operations, uranium-bearing equipment on the periphery of the hoods is nearly unreflected. BL process equipment within the hoods may be incidentally reflected. Incidental reflection includes operator body parts, the thin-walled stainless steel of the hood, distant room walls or floor, etc. Of these reflectors in close proximity to uranium, none are infinite in effective thickness. The concrete walls and floors may be thick but are far enough from the uranium on the hood floor that their effectiveness as a reflector is diminished. Thus the nominal reflection modeled is bounding of the credible reflection that could occur. A box of water is modeled around the leachate columns and the containers in the hoods with the exception of the hood floor which is modeled as 0.1875-inch thick stainless steel. The hood floor is more than 2 ft above the concrete floor and nothing is stored under the hoods. The hood floor is dry under normal conditions based on the nature of the process; spills or other events that could result in liquid accumulation are discussed in Section 5.3.

5.2 Normal Conditions

The feed materials to be dissolved in 30% nitric acid are described in Table 1including the form, mass limit, feed container and expected moderation level. The geometry and volume of the containers and equipment in the BL process are given in Table 2.

5.2.1 Equipment Outside the Hoods

Most uranium-bearing equipment on the periphery of the hoods has limited neutron interaction with process containers in the dissolution and filtration workstations because the two systems are either de-coupled by large separation distances (i.e., greater than 1-2 ft) or misaligned (i.e., small solid angle). In Room X, neutronic coupling occurs between BL process containers in each hood and safe bottles. Hood A also has peripheral equipment that may potentially interact with process containers in the hood. The bottoms of the leachate columns are elevated more than 41 in. above the hood floor. At this height and slight offset, the parallel leachate columns are de-coupled from process containers in the hood and from the 2 in. deep pans on the shelf 23.5 in. above the hood floor. The columns are not, however, de-coupled from themselves. The individual subcriticality of these 6 in. nominal diameter leachate columns has been demonstrated in Reference 4 when filled with uranyl nitrate solution at optimal uranium concentration for nominal (1-in.) water reflection. The wall of the Pyrex column was modeled but no credit was taken for the boron-10 neutron poison in the Pyrex as the boron was modeled as 100% boron-11. Because the columns are located several feet off the process floor, it is not possible to surround (e.g., by flooding or human interaction) them with more than the equivalent of an inch of full density water. The leachate columns are installed with 24 in. ± 0.25 in. of c-t-c spacing between them as shown on drawing X-2. Calculations in Reference 4 demonstrate that two 6.186-in. inner diameter columns spaced 18 in. c-t-c are subcritical. The columns are reflected by a 1-in. thick water box surrounding them and are modeled 96-in. long which is much greater than the 36-in. actual length. Thus the leachate columns are subcritical.

Table 1. Feed Materials

Uranium Form	Mass limit and Container	Moderation Under Normal Conditions
Uranium metal chips, turnings, fines	≤ 5 kg "dry" net weight or 3 kg "wet" net weight in a hospital can, ≤ 10 kgU in a modified hospital can	Unlimited hydrogen-to-fissile nuclei ratio (H/X) for "wet" loading (kept under liquid)
Scrap metal and metal clinkers	≤ 10 kgU in a modified hospital can	Dry
U_3O_8 or UO_3	≤ 20 kg net weight "dry" in a hospital can or green salt can	UO_3 is hygroscopic and may form a stable monohydrate; U_3O_8 is dry
BL roughing filters	Unlimited but not expected to be greater than 250 gU each	Dry filter material with possible elevated H/X
Contaminated combustibles	Uranium-bearing material in small or large plastic bags	Dry to damp, unlimited H/X and C/X ratios

The wet vacuum trap is more in the plane of the hood floor, with the edge of the trap approximately 4 in. from the hood's edge. A safe bottle may also be brought to the hood into which solutions are transferred. The top of the safe bottle would also be in the plane of the hood floor. The wet vacuum trap and safe bottle may be volumetrically full of solutions. From ANSI/ANS-8.1-1998 [5], the subcritical fully water-reflected cylinder diameter for uranyl nitrate solution is 14.4 cm (5.66 in.). Therefore, safe bottles with a maximum outer diameter of 4.475 in. and the wet vacuum trap with a maximum inner diameter of 4.118 in. are subcritical individually under optimum conditions. Interaction between the safe bottle and wet vacuum trap is bounded by the evaluation of the 6-in. diameter columns discussed in the previous paragraph. The trap and safe bottle are smaller in diameter and are spaced greater than 20 in. c-t-c. Interaction of the safe bottle and wet vacuum trap with the containers in the workstations is evaluated in subsequent sections. Other uranium bearing equipment is more than 4 ft from the hoods such that interaction with other equipment need not be evaluated.

5.2.2 Interaction Analysis

The combination of containers at the workstations during normal conditions is shown in Figure 4. This combination is shown to be subcritical by comparison to a critical experiment and by calculations performed with KENO-V.a. The experiment and calculations are described below and will be referenced throughout the CSE in the evaluation of specific normal and upset configurations.

Table 2. Container and Equipment Dimensions

Container or Equipment	Outer Diameter (in.) unless noted	Outer Height (in.) unless noted	H/D Ratio	Volume (L) [1]
4-L Kimax Erlenmeyer flask [2]	2.375 (inner upper) 8.25 (inner lower)	15.125	N/A	4.411 [3]
1.86-L Buchner funnel	7.562 (inner upper) 0.744 (inner middle) 0.482 (inner lower)	3.227 (upper) 3.25 (middle) 4.529 (lower)	N/A	3.281 [3]
4-L beaker	7 (max inner) 6.772 (calc)	6.343 (calc) [4] 6.772 (calc)	0.91 1	4 (given)
Green salt can	6	12.75	2.13	5.91
Modified hospital can	7.375	4 (inner)	0.54	2.80
Hospital can	7.0625 (given)	7.25 (calc)	1.03	4.65 (given)
Sample bottle	1.59 (calc) [5] 2.27 (calc)	4.625 (given) 2.27 (calc)	2.91 1	150 mL (given max)
Pan	9 wide × 24 long (inner)	2 (inner)	N/A	7.08
Safe bottle	4.475 (outer)	54	12.07	13.92
Wet vacuum trap	4.531 ± 0.068 (outer) 0.266± 0.025 (wall) gives 4.118 (max inner)	24	5.83	5.238
Leachate columns	6.186 (inner) glass pipe	36	5.82	17.72

1. Volume is calculated from the dimensions unless noted as given. If volume is given, calculated dimension is noted.
2. Kimax Erlenmeyer flask is slightly larger than, and thus bounding of, the Pyrex Erlenmeyer flask.
3. The calculated volumes for the conical portions of the flask and funnel were determined using the relationship for the frustum of a right circular cone: $V=1/3 \cdot B \cdot h \cdot (R_1^2 + R_2^2 + R_1 \cdot R_2)$.
4. This height corresponds to a 4-liter cylinder with a maximum diameter of 7 inches. Dimensions that result in an H/D ratio of 1 are also given.
5. This diameter corresponds to a 150 mL cylinder at the maximum height of 4.625 inches, ignoring the wall thickness. Dimensions that result in an H/D ratio of 1 are also given.

5.2.2.1 Critical Experiment

From Table 44 of LA-10860 [6], seven 0.15-cm thick aluminum cylinders, 20.3 cm in diameter, filled to 18.3 cm with 538 g ^{235}U/L U(93.2)O_2F_2 solution are critical when triangularly spaced 0.38 cm (0.15 in.) apart in air (nearly touching) and unreflected. Considering hood and container wall thicknesses as well as the irregular shape of the flask and funnel, a 0.15 in. average edge-to-edge equipment spacing is realistic for the BL equipment array. The wall thickness of the cylinders in the experiment is 0.15 cm, which is slightly less than 0.0625 in. This thickness is comparable to the wall thickness of the metal beaker and cans but is less than the wall thickness of a glass flask. The volume of the 5.9-L experimental cylinders bounds the 4-L beaker and flask. The H/D ratio of the experiment cylinders is 0.9 which is very comparable to the 4-L beaker and closer to optimum (i.e., one) than the other equipment as shown in Table 2, with the exception of the hospital can. However, the hospital can is limited to dry loadings which will be less reactive than the experiment cylinder filled with solution. Additionally, the seven unit hexagonal array contains more units than allowed at a dissolution or filtration workstation. For these reasons, this critical experiment is bounding of up to seven pieces of equipment in a BL hood. However, there is no reflection of the units in the experiment. For that reason, calculations with nominal reflection were also performed as discussed in the next subsection.

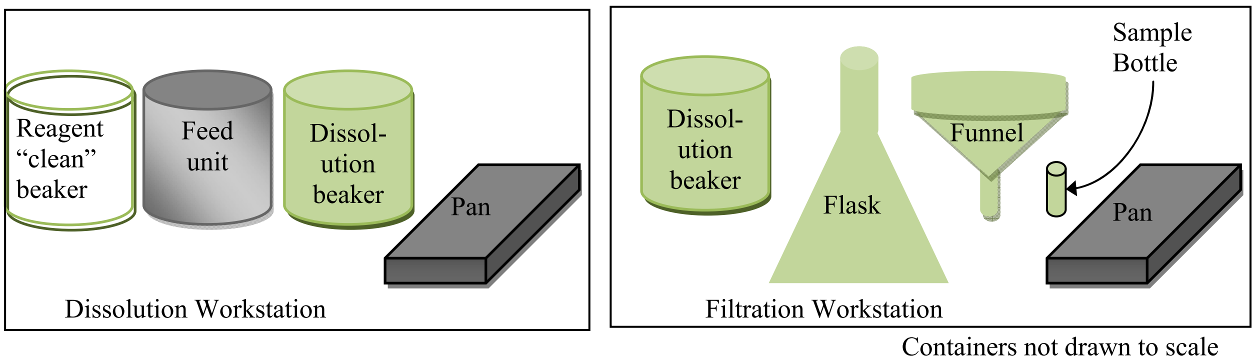

Figure 4. Container/Equipment Layout at the Workstations

5.2.2.2 Calculations

Of the pieces of equipment that can be in or against the BL hoods (i.e., safe bottles, 4-L Erlenmeyer flask/1.86-L Buchner funnel combination, 4-L beaker, feed unit and pan), the 4-L dissolution beaker is the most reactive single unit. This supposition is based on the combination of beaker volume and optimum cylindrical geometry (H/D ratio of 1). The pan has a slab-like geometry, resulting in tremendous neutron leakage. The flask has a slightly greater volume than the beaker, but its shape results in greater neutron leakage. The Buchner funnel has a similar, irregular shape as the flask but with a smaller volume. The safe bottle has a much larger volume than the beaker, but its long, skinny shape results in significant neutron leakage. Additionally, the safe bottles remain outside of the hood and thus the interaction is reduced compared to the equipment inside the hood.

A 2 × 2 array of beakers was modeled with 1-in. tight fitting water on five sides of the array and the 0.1875-in. thick stainless steel floor modeled below the containers. The beaker geometry was modeled in two ways: 1) using the maximum diameter from Table 2; and 2) with a smaller diameter but an H/D ratio of 1. The beakers were filled with uranyl nitrate solution modeled using the SCALE standard composition, solnuo2(no3)2, and the uranium concentration of the 100% enriched solution varied to determine the optimum value. Based on the results in Table 3, the maximum $k_{eff} + 2\sigma$ value of 0.9094 occurs for beakers at an H/D ratio of 1 with solution containing 350 gU/L. Example input files are given in Appendix B. The solution height is taller in beakers with an H/D ratio of 1 such that when the beakers are modeled together and the effective diameter is very large, the taller height results in a more favorable H/D ratio for the beaker array. (Beakers could be even taller and skinnier to optimize the configuration but since beakers used are all similar and near the maximum diameter, this was not deemed necessary.)

Table 3. Calculations of Beaker Leaching Container Arrays

Case Name	Uranyl Nitrate Solution Concentration (gU/L)	k_{eff}	σ	$k_{eff} + 2\sigma$
2 × 2 array of beakers, each at max radius of 7 in.				
4beaker300	300	0.8895	0.0011	0.8917
4beaker350	350	0.8898	0.0010	0.8918
4beaker400	400	0.8883	0.0010	0.8903
2 × 2 array of beakers, each with H/D ratio of 1				
4beaker250h	250	0.90250	0.00094	0.9044
4beaker300h	300	0.9055	0.0010	0.9075
4beaker350h	350	0.9074	0.0010	0.9094
4beaker400h	400	0.9042	0.0011	0.9063
4beaker450h	450	0.8990	0.0011	0.9012
Pan added in contact with beaker array (H/D ratio of 1)				
4bpan	350	0.8921	0.0014	0.8949
Safe bottle and pan added in contact with beaker array (H/D ratio of 1)				
4bpsb	350	0.9078	0.0010	0.9098
Infinite array of 3 ft 6 inch wide workstations as shown in Figure 5				
4base	350	0.9220	0.0012	0.9244

Two additional items were added to the 2 × 2 beaker array. First a pan filled with fissile solution was modeled next to the array. One pan is allowed on the hood floor in both the dissolution and filtration workstations. The 2-in. height of the pan makes it much less reactive than a beaker and thus it is modeled explicitly instead of as a beaker to make the model more realistic. A 1-in. thick water reflector is modeled on the top and sides of the beaker and pan array as shown in Figure 5. The 1-in. water reflection is around and on top of the containers but is left off of the infinitely reflected side to allow for interaction between containers in the two workstations. A slight decrease in k_{eff} is observed when the pan is added because the addition of the pan pulls the water reflector away from the beakers. A safe bottle is also modeled on the end of the array as shown in Figure 5. This configuration bounds the actual scenario where the safe bottle remains outside the hood and thus will not be in direct contact with the beakers. Instead of extending the water reflector box around the safe bottle, the box remains around the beakers and pan and the safe bottle is separately reflected by a 1-in. thick water reflector which is cut off on the side of the beakers as shown in the figure. The safe bottle is modeled sitting on a concrete floor with the beakers 26.875 in. above the floor. This height is representative of the actual configuration and the full height of the beakers interacts with the safe bottle.

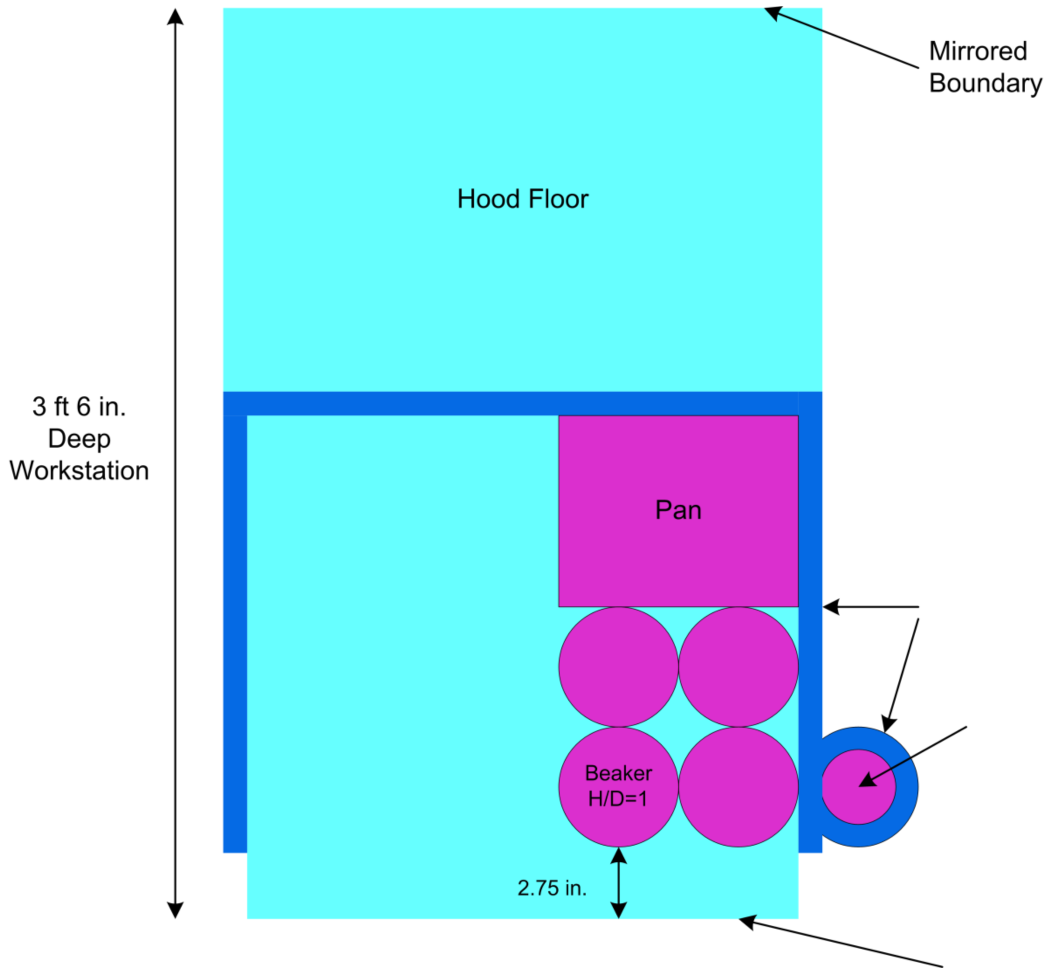

Figure 5. Top View of Workstation Model with 2 × 2 Array of Beakers, Pan and Safe Bottle

Next, the configuration of 6 items described above was mirrored 5.5 in. from the first 6 items to model operations in two adjoining hood workstations. The dividers provide a minimum of 7.375 in. between workstations but the space between the two hoods is a minimum of 5.5 in. The configuration was mirrored such that the beakers are closest to one another and the pans are furthest away as they provide little interaction. In the reflected condition, there is a safe bottle in front of each workstation separated by 5.5 in. whereas only one safe bottle is brought up to each hood. The reflected surfaces are shown in Figure 5. The modeled configuration also bounds interaction between the containers in the hood and the safe bottle and wet vacuum trap on the end of hood A as shown in Figure 1. The safe bottle staging location is more than 5.5 in. from the edge of the hood and the wet vacuum trap is much thinner than a beaker and further from the front of the hood. The resulting $k_{eff} + 2\sigma$ value was 0.9244 as given in Table 3.

Finally, one of the four beakers was replaced with a feed can to confirm that the solution filled beaker bounds the feed can. The feed can contains either 10 kg dry U metal, 3 kg wet U metal or 20 kg dry U_3O_8 or UO_3. The 10 kgU(100) metal was modeled as a sphere at 18.81 g/cm^3 with a radius of 1.98 in. (5.025 cm). The sphere was modeled in contact with the other beakers. The 20 kg oxide loading was modeled as U_3O_8 at an H/X ratio of 3 in both a green salt can and a can with an H/D ratio of 1. U_3O_8 has a higher uranium density than UO_3 and thus results in a higher reactivity for a fixed net weight. The results in Table 4 confirm that the solution filled beaker bounds the feed can of dry material. The modeled feed cans are also bounding of a plastic bag with dry/damp uranium-contaminated materials due to the low uranium mass (limited to 350 g-^{235}U per CSE-CONT) and low uranium density of the dry contaminated materials. BL roughing filters are not expected to contain greater than 250 g-^{235}U per filter. Roughing filters must be run through the process as a set from a hood and hood A has the most roughing filters at eight. Thus, the 10 kg metal loading is bounding of a hood's worth of filters going through the process. Roughing filters, combustibles, and wipes left in the hoods to dry are not included in the analysis because they have negligible uranium contamination after being treated with nitric acid as part of the BL process.

A hospital can is also allowed to contain 3 kg net weight of "wet" uranium and a modified hospital can is allowed to contain up to 10 kg net U in any form, which may be wet. The modified hospital can volume is only 2.8 L which leaves little room for moderation. Instead, the 3 kg net weight wet hospital can loading is modeled. The H/X ratio is varied while maintaining the overall weight of the U and water at 3 kg. The volume of this loading does not exceed 4 L so it is modeled in the beaker to the appropriate height instead of using a hospital can. The results as given in Table 4 show that the maximum value of 0.8586 occurs at an H/X ratio of 125. Again, this feed can is less reactive than the 4-L beaker of solution.

These calculations were performed using SCALE 5 KENO-V.a [2] with the 238-group ENDF/B-VI cross section library to demonstrate the subcriticality of these configurations. The calculations were run with the CSAS25 analytical sequence on a Hewlett Packard Series ZZZ workstation which is maintained under configuration control by the Nuclear Criticality Safety group. The inputs and outputs are archived in directory xxx/cse-bl on the workstation. The USL is 0.957 as discussed in Section 4.0.

Table 4. Calculations of Container Array with Feed Can

Case Name	Feed can contents replacing beaker†	k_{eff}	σ	$k_{eff} + 2\sigma$
4bm10	10 kg-U metal sphere	0.8513	0.0010	0.8177
4box20gs	20 kg-U_3O_8 (H/X ratio = 3) in green salt can	0.8964	0.0010	0.8984
4box20	20 kg-U_3O_8 (H/X ratio = 3) in cylinder with H/D ratio of 1	0.9134	0.0010	0.9154
4b3m	3 kg metal sphere (H/X ratio =0)	0.8153	0.0012	0.8177
4b3mh50	3 kg net weight U-water at H/X ratio =50	0.8431	0.0010	0.8451
4b3mh100	3 kg net weight U-water at H/X ratio =100	0.8547	0.0010	0.8567
4b3mh125	3 kg net weight U-water at H/X ratio =125	0.8554	0.0016	0.8586
4b3mh150	3 kg net weight U-water at H/X ratio =150	0.8549	0.0014	0.8577

† Each case begins with a 2 × 2 array of beakers, pan and safe bottle filled with 350 gU/L solution as found to be most reactive in Table 3. Each beaker has an H/D ratio of 1.

5.2.3 Dissolution Workstation

Each dissolution workstation is limited to the following containers with no spacing required between containers:

- one feed unit,
- one 4-L dissolver beaker,
- one 4-L "clean" beaker for 30% nitric acid or water, and
- one pan for feed material sorting.

Uranium-bearing material is removed from the feed can and dissolved in a 4-L dissolver beaker. Uranium-bearing material may be sorted in a pan before dissolution. The 4-L "clean" beaker does not contain uranium under normal operations. Thus, under normal conditions, a feed can, a beaker and a pan may contain fissile material. Additionally, since there is no requirement stating which workstation must be used for dissolution vs. filtration, a safe bottle could be in front of the workstation.

The normal configuration described above is bounded by the 2 × 2 array of 4-L beakers with a pan and a safe bottle adjacent to the array that was shown to be subcritical in Section 5.2.2.2. All containers are in contact with one another. Calculations were also run to prove that a 4-L beaker filled with optimum concentration uranyl nitrate solution is more reactive than the 10 kg metal, 20 kg oxide, or 3 kg net weight wet metal loadings allowed in a feed can or the contaminated combustible loading. Also, the feed can, pan and beaker are not likely to all be full since the beaker and pan are fed from the feed can.

Containers may also be passed over one another in the same workstation or when transferring between workstations. There are two excess beakers beyond the normal condition modeled in the 2 × 2 array which adequately account for containers passing over containers on the hood floor. Also, moving a container over another container is less reactive than 2 containers side by side due to the larger solid angle between containers in the side-by-side vs. the end-to-end configuration. The container passed over is also outside the plane of the other containers on the hood floor.

5.2.4 Filtration Workstation

Each filtration workstation is limited to the following containers with no spacing required between containers:

- one 4-L dissolver beaker that is brought over from the dissolution workstation,
- one 4-L Erlenmeyer flask
- one 1.86-L Buchner funnel and filter media,
- one pan for the collection of filtered solids, and
- one sample bottle.

The feed unit is not permitted at the filtration workstation. Because the sample bottle solution volume is small and filled with solution taken from the dissolver beaker or Erlenmeyer flask, it is conservative to treat the solution as part of the beaker or flask; thus, sample bottles will be ignored in the remainder of the analysis. There is no requirement stating which workstation must be used for dissolution vs. filtration so a safe bottle could be in front of the workstation.

It is permissible after filtration for the 4-L dissolver beaker to be returned to the dissolution workstation, be refilled, and sent back to the filtration workstation before the 4-L Erlenmeyer flask is emptied into a safe bottle or wet vacuumed to a leachate column. Thus, a full 4-L dissolver beaker, full 4-L Erlenmeyer flask, a full safe bottle, and a pan of filtered solids could be present at the filtration workstation. A filled pan is considered conservative, but credible, as a normal condition, although the operator would likely place a filled pan onto the shelf. The pans on the shelves are a minimum of 23.5 in. off the hood floor and approximately 8.5 in. above the tallest piece of equipment, the 4-L Erlenmeyer flask. The shelf is over 15 in. above the top of a beaker or feed can. Thus, the pan shelves do not contribute significantly to the reactivity of the containers on the hood floor and are evaluated separately in Section 5.2.6.

The normal configuration described above is bounded by the 2 × 2 array of 4-L beakers with a pan and a safe bottle adjacent to the array which was shown to be subcritical in Section 5.2.2.2. All containers are modeled in contact with one another. The flask has a slightly greater volume than the beaker, but its shape results in greater neutron leakage. The Buchner funnel is on top of the Erlenmeyer flask but both the flask and funnel will not be full as the flask has an outlet near the top that functions as an overfill drain hole. Also, when the funnel is set on the hood floor, it is not capable of retaining liquids due to the design of the open bottom that does not allow the funnel to sit upright sealed with the floor. (In the upset condition where liquid accumulate on the hood floor, the depth within the funnel will be the same as that outside the funnel.) The pan will contain filtered solids but is conservatively modeled filled with uranyl nitrate solution.

The modeled container array is conservative because the actual process has two fewer containers of fissile material, the geometry of the flask is less reactive than the modeled cylinder, solution concentrations are not optimum in the actual operation, pans are not full of fissile solution, and excess acid is likely present in the solution.

5.2.5 Interaction between Adjacent Workstations

The interaction between containers in adjacent workstations must also be considered. The dividers between workstations are 7.375 in. wide but the two hoods are only 5.5 in. apart. Thus, the worst case normal condition is to have a workstation 5.5 in. from another workstation. The containers in a dissolution or filtration workstation were both shown to be bounded by a 2 × 2 array of beakers with an adjacent pan and safe bottle. To model adjacent workstations, the set of containers is modeled 2.75 in. from the end of a 3-foot 6-inch wide workstation and the ends of the workstation are mirrored to represent an infinite workstation array. With the reflected condition, beakers in adjacent workstations are 5.5 in. edge-to-edge. The modeled configuration is illustrated in Section 5.2.2.2 and the $k_{eff} + 2\sigma$ value is 0.9244.

Containers may also be passed over one another in the same workstation or when transferring between workstations. The two excess beakers beyond the normal condition for either workstation modeled in the 2 × 2 array adequately bound a container passing over containers on the hood floor. Also, moving a container over another container is less reactive than 2 containers side-by-side as discussed above.

5.2.6 Pan Shelves

In the back of each hood, there is one continuous shelf for pans that is approximately 10-in. wide, at most 148.125-in. long, and a minimum of 23.5 in. above the hood floor. Pans have an inner width of 9 in., inner height of 2 in., and inner length of 24 in. At these dimensions, filling a pan shelf in hood A or B requires six pans.

CSE-CONT restricts pans to wet salvage, solutions, sludge, slurries, and residues containing no UO_2 or U metal. These materials may be loaded until the pan is volumetrically full. The BL filtering operation does not generate UO_2 solids, but could generate U metal. Noticeable metal pieces are returned to the 4-L dissolver beaker for further dissolution. From Figure 2.4 of TID-7016 [7], the safe subcritical thickness for an infinite solution slab with 1-in. water reflector is 76 mm (3 in.). Nominal reflection is appropriate for the shelf which is suspended above the hood floor and well below the top of the hood. The basis for safety is, therefore, a combination of limited depth of material in pans, form of material in pans, and administrative requirements prohibiting stacking or overfilling.

The tallest piece of process equipment is the 4-L Erlenmeyer flask at approximately 15-in. This affords at least an 8.5-in. spacing from the top of the flask to the bottom of the pan shelf. The majority of solution is not located in the flask neck but more than 12 in. from the shelf in the body of the flask. There is over 15 in. of spacing between the top of a beaker or feed can to the pan shelf. Thus, the neutron interaction between BL equipment on the hood floor and the pan shelves is minimal. The normal condition that must be evaluated involves the neutron interaction of a full pan shelf with a 4-L dissolver beaker being moved from the dissolution workstation to the filtration workstation as the beaker may be lifted into the same plane as the pans on the shelf.

Figure 84 of TID-7028 [8] gives critical data for a slab of $U(93.2)O_2F_2$ solution interacting (side-by-side) with a cylinder. UO_2F_2 solution bounds the uranyl nitrate solution produced in the BL process due to the increased neutron absorption in nitrate solutions. With the slab and cylinder in contact with one another, the critical height of solution in each item is 37 cm (14.5 in.). The uranium concentration of solution in the critical experiment is 77.9 g/L and the H/U ratio is 331, which is near optimal based on the calculations in Section 5.2.2.2. The slab and cylinder are not reflected other than the aluminum vessels they are contained in, which is similar to the reflection on the pan shelf. The cylinder is 9.88 in. in diameter, which is significantly larger than any process container in the BL process. The 14.5-in. solution depth in the slab is more than seven times that of a pan. The length of the slab, 47.63 in., and slab width, 5.9 in., are less than the shelf length and width, but the volume, neutron interaction, and reactivity are greater for the narrower, taller slab. Thus, the pans on the shelf will remain subcritical.

5.2.7 Exhaust System

In Room X, the exhaust travels beyond the hood filters into a plenum and then through vertical ductwork down to the basement on to Stack 99. The BL process boundary is the floor and the remainder of the ductwork is in the Stack 99 system.

Although the mass of uranium in the ventilation system is not controlled, the buildup of uranium is limited by the nature of the operation. Uranium in solution does not generate airborne particles. Uranium in solid form, such as that found in the feed units, generates airborne particulate when handled, but the amount carried into the ventilation system is extremely limited due to the heavy nature of uranium. The roughing filters also limit the amount carried into the ventilation system. Process history has shown that the small amount of uranium that does enter the ventilation system fans out fairly evenly.

The process-based limitations and controls discussed above constitute sufficient barriers to the accumulation of significant uranium mass. Therefore, specific exhaust system mass controls are not necessary. The exhaust plenum in the back of the hoods is a horizontal surface where fissile material could accumulate within the BL boundary. Because the plenum is difficult to gamma monitor due to its location next to the wall, periodic cleanout of the plenum floor is required. The plenum floor is just below the opening for the roughing filters such that it is accessible when the roughing filters are removed.

5.3 <u>Unlikely Events (Contingencies)</u>

Contingencies were identified using a What-if Checklist. This method was chosen because the process is relatively simple and the operations are manual. A team consisting of representatives from Criticality Safety, Process Engineering and the operators who will operate the BL process met to identify the hazards associated with the operation in relation to the controlled parameters. The resulting What-if Table is given in Appendix A and the hazards requiring additional analysis are discussed below.

5.3.1 Excess Fissile Containers in a Workstation

This upset condition could occur if 1) a second feed unit is inadvertently brought to a dissolution workstation, 2) a dissolver beaker or flask is inadvertently brought from an adjacent workstation, 3) fissile material is added to the beaker of reagent, 4) a full pan is left on the hood floor when another pan is brought in, 5) a feed can is brought into the filtration workstation, 6) dissolution and filtration are performed in the same workstation or 7) an additional container is brought to the hood while being transported through the area.

This upset condition results in one of the following combinations of containers in a workstation:

1) two feed cans, beaker and a pan or
2) feed can, beaker and pan or beaker, flask and pan with additional flask or beaker or
3) feed can, 2 beakers, and pan or
4) feed can, beaker and 2 pans or beaker, flask and 2 pans or
5) feed can, beaker, flask and pan or
6) feed can, beaker, and pan with additional flask and second pan or
7) feed can, beaker and pan or beaker, flask and pan plus additional container outside hood in close proximity.

Thus, there are a maximum of 4 containers, including at least one pan, in a workstation plus the workstation may be adjacent to a safe bottle. As discussed in Section 5.2.2.2, a feed can, flask or pan is bounded by a 4-L beaker. Thus, the 2 × 2 array of beakers with a pan and safe bottle in adjacent workstations as shown to be subcritical in Section 5.2.2.2 bounds this upset condition as the modeled condition contains 6 containers. The type of excess container that may be brought up to the hood varies but a 4-L beaker filled with optimum concentration fissile solution bounds the other container as 1) the other container will not be a tight packed arrangement with the beakers since it is outside the hood, 2) other dry container loadings are bounded by the evaluated dry feed can with 10 kgU metal or 20 kgU oxide loadings which was shown to be less reactive than the 4 L beaker and 3) allowed wet can loadings are limited to a maximum of 3 kg net weight or a very small volume. Thus, this contingent condition remains subcritical and the loss of control of another parameter, such as moderation, is needed before a criticality accident can occur.

5.3.2 Feed Can Approved for Dry Loading is Optimally Moderated

This contingency could occur if 1) an improperly moderated feed can was brought to the BL hood or 2) the operator poured the reagent (nitric acid or demineralized water directly into the feed can instead of adding the feed to the reagent in the dissolver beaker. Spills of fissile solution or nitric acid that create fissile solution in the feed unit are evaluated in Section 5.3.6. Attempting to use a feed can in place of a 4-L dissolver beaker would be an egregious error involving violation of BL procedures and procedures for container loadings in order to transfer dissolving liquids directly into a feed can. Spills of uranyl nitrate solution, water, or nitric acid from the 4-L dissolver beaker into the feed can are more credible but it is unlikely that the feed can would be completely filled with liquid as analyzed below. If the feed can is empty at the time of the spill and is filled with water or 4 L of optimum concentration beaker solution, the solution volume is the same as modeled in the 4-L beaker and is bounded by the normal condition analysis. If the feed can is filled with material at the same time that water is added, the result of the addition will be dependent upon the form of the feed material. A case-by-case study of feed materials is presented below.

5.3.2.1 U_3O_8 or UO_3

The green salt can has the largest volume of the cans used for oxide and thus will hold the most moderator. Water was added to the base loaded can (20 kg net weight loading) and the maximum H/X ratio was determined to be 6.2 when the material filled the can. A dissolution workstation contains a feed can, dissolution beaker and pan. The calculation model thus contains a green salt feed can and a beaker of fissile solution next to a pan and safe bottle. The modeled container configuration is similar to the base model with 4 beakers but the second row of two beakers has been removed and the pan slid up against the remaining two containers as shown in Figure 6. The 1 in. water reflection is around and on top of the containers but is left off of the infinitely reflected side to allow for interaction between the containers in the two workstations. The calculation result for this case, *2box20gswet*, is 0.8398 ± 0.0011, which is well below the USL of 0.957.

5.3.2.2 Scrap, Clinkers, Chips, Turnings, Fines,

Uranium metal chips, turnings, and fines having a "wet" net weight up to 3 kg have already been evaluated under normal conditions. Uranium metal chips, turnings, and fines, scrap metal and metal clinkers with a mass up to 10 kg-U are normally dry. This scenario considers maximum moderation in a hospital can, the largest volume can approved for metal loadings. Although a hospital can is normally limited to 5 kg-U, this analysis considers the 10 kg-U mass limit for the modified hospital can in a larger hospital can.

The metal turnings, etc. are expected to be in small pieces such that the U metal is modeled in a homogeneous mixture. Filling a hospital can with 10 kg-U and water results in a maximum H/X ratio of 10.7. The model shown in Figure 6 was used with the moderated hospital can as the feed can. The result of this case, *2b10mwet*, is 0.9110 ± 0.0010 which is below the USL of 0.957. Thus, this contingent condition remains subcritical and the loss of another controlled parameter, such as mass, is needed before a criticality accident can occur.

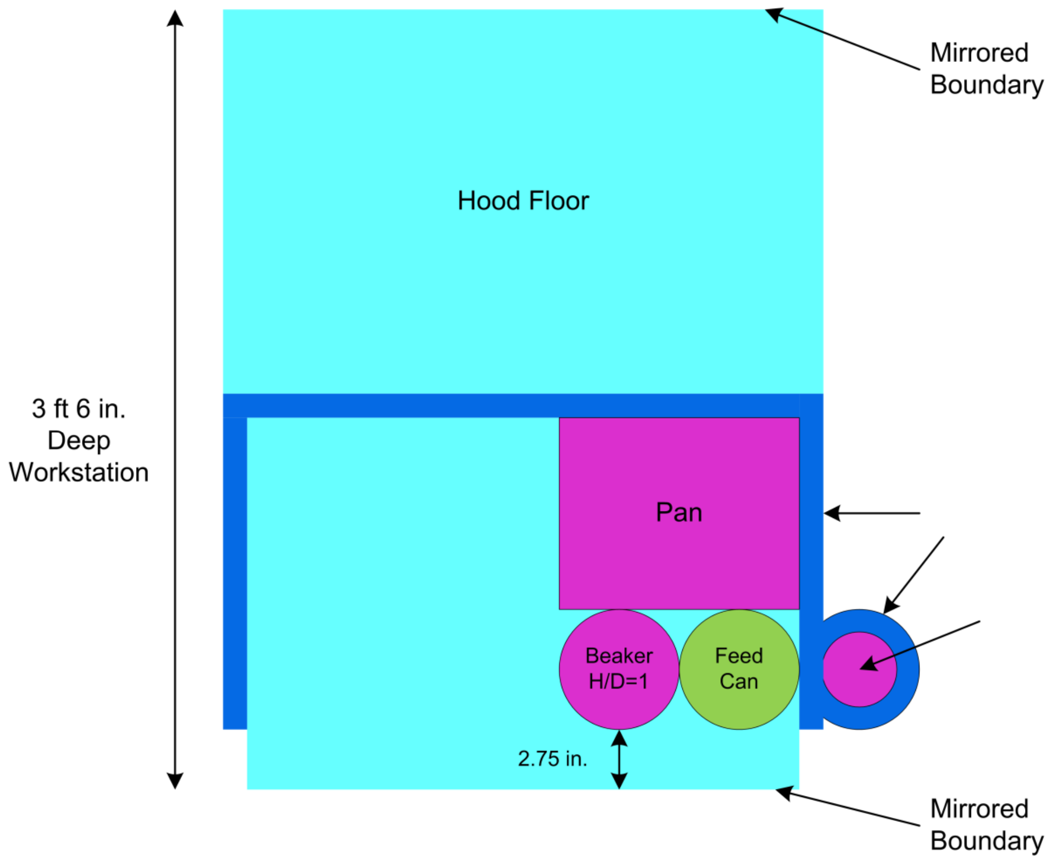

Figure 6. Top View of Workstation Model with Feed Can, Beaker, Pan and Safe Bottle

5.3.3 Feed Unit Overloaded

This contingency could occur if an overloaded feed can was brought into a BL hood. This is unlikely because cans are weighed, batched and entered into accountability when they are loaded in other upstream processes.

Recall that the feed unit mass limits for solid forms of uranium are:

- A hospital can or green salt can loaded with up to 20 kg net weight UO_3 or U_3O_8, OR
- A hospital can loaded with up to 5 kg net weight dry U metal or 3 kg net weight wet U metal as U metal chips, turnings, and fines, OR
- A modified hospital can loaded with up to 10 kgU as U metal chips, turnings, fines, sludge, scrap, and clinkers, OR
- A large or small plastic bag of combustibles with up to 350 g-^{235}U, OR
- Roughing filters from a BL hood.

The mass of uranium in a feed can far exceeds that on combustibles in a plastic bag or the uranium holdup on roughing filters; therefore, an overload of a feed can is the bounding contingency.

Uranium metal chips, turnings, and fines having a "dry" net weight up to 5 kg may be handled in a hospital can or a mass up to 10 kgU may be handled in a modified hospital can. A 20 kg sphere was modeled next to a beaker, pan and safe bottle in the infinitely reflected workstation model shown previously in Figure 6. The resulting k_{eff} was 0.8493 ± 0.0010 of this case, *2b20m*.

Uranium metal chips, turnings, and fines, having a "wet" net weight up to 3 kg, may be handled in a hospital can. A hospital can containing 10 kg-U metal loading was shown to be subcritical when fully flooded along with a beaker, pan and safe bottle in the infinitely reflected workstation model in Section 5.3.2.2. The net weight of the hospital can contents as modeled is 14.1 kg, which is an over-batch of the allowed loading by more than a factor of four.

The largest volume can approved for oxide loadings, the green salt can, was modeled as being volumetrically filled with U_3O_8 at an H/X ratio of 3. The can contained 29.5 kg net weight. The case, *20box20gsf,* has a k_{eff} of 0.8493 ± 0.0010.

Thus, an overloaded feed can will not result in a criticality accident without the loss of control of another controlled parameter.

5.3.4 Large Quantities of Demineralized Water or Nitric Acid Spill in the Hoods

This contingency addresses a spill of reagents during transfer, a leak in a supply line such that reagent flows uncontrolled into the hood or a sprinkler activation outside of the hood. These events may result in abnormal reflection. A spill on the hood or facility floor is evaluated. (A spill of fissile solution into a feed can is evaluated in Section 5.3.6.) First, water is modeled on the hood floor 3-in. deep. The configuration of the drain holes in the hood has been shown to limit liquid accumulation to no more than 3 in. above the stainless steel hood floor [9]. The workstation dividers do not go to the hood floor such that liquids on one section of the hood floor will slab out along the entire length of the hood. Water bounds the other reagents as it is both a better moderator and reflector. A spill of this magnitude is unlikely as reagents are handled in a 4-L beaker. Also, accumulation of sprinkler water to this depth is unlikely because the hoods have a continuous metal roof. A leak from a reagent line is expected to begin as a drip that would be contained by the operator before it flooded the hood floor. Also, if the leak occurred when no one was present, fissile material would not be present in the hood and there would be no criticality safety impact.

A dissolution or filtration workstation contains two containers that may be filled with fissile material, either a feed can and dissolution beaker or a dissolution beaker and Erlenmeyer flask, in addition to a pan. A beaker and feed can filled with fissile solution were modeled next to a pan and safe bottle with 3 in. of water on the hood floor in the configuration shown previously in Figure 6. The feed can is a hospital can containing 10 kg-U metal which is full of water, as the reagent may also spill into the feed can. The limited volume of the hospital can limits the H/X ratio to a maximum value of 10.7. If nitric acid spills into the container, uranyl nitrate solution will form which is bounded by a solution filled beaker. The modeled configuration was shown previously in Figure 6. The 1-in. thick water reflector around the containers was still modeled above the 3 in. of water on the hood floor. The result of this case, *2b10mwater*, is 0.9450 ± 0.0010, which is less than the USL of 0.957.

Roughing filters or a plastic bag of contaminated combustibles may be present on the hood floor when the spill occurs. The corners of the plastic bag are required to be cut such that the liquid will still slab out along the length of the hood, but the liquid may now contain uranium from the filter or bag. This scenario is bounded by the spill of uranyl nitrate solution discussed in the next subsection.

Thus, the double contingency principle is met for this upset as the modeled loss of reflection control remains subcritical and control of another parameter must be lost before a criticality accident is possible.

5.3.5 Uranyl Nitrate Solution Spills in Hood or Spills on Floor

5.3.5.1 Spill Inside the Hoods

This subsection evaluates an unlikely, large volume, uranyl nitrate spill in the hoods. The dissolver beaker is transferred to the Buchner funnel, which has a large diameter (> 4 in.) for easy transfer. The wet vacuum system is used to transfer the solution from the flask to the leachate columns and may also be used for other transfers. The wet vacuum transfer system reduces the likelihood of spills as the operators do not need to manually pour full containers. The largest volume of optimally-concentrated solution available at a workstation is 8.411 L from a 4-L dissolver beaker and a 4-L Erlenmeyer flask. Pans do not contain solution but filtered solids. Vigorous reactions, including excessive bubbling, splattering of solution, and overflowing of the 4-L dissolver beaker or flask could occur but it is unlikely that both containers would be completely full and spill at the same time. Also, wet vacuum is connected to the flask during filtering to aid in pulling the solution through the filter; thus excess material from the flask would be transferred to the leachate columns instead of spilling into the hood. It is not considered credible for a safe bottle to be spilled into the hood as it is chained to the hood and capped prior to movement.

The minimum hood floor dimensions are 157 in. by 29.75 in. for a floor area of 4670.75 in^2. If both the 4-L dissolver beaker and 4-L Erlenmeyer flask were to spill all of their solution, the solution would form a slab no more than 0.28-cm thick. Note: The spillage of uranyl nitrate solution in one workstation by an operator is independent of the spillage at another workstation in the same hood. However, a common mode failure, such as an earthquake, could cause the failure of all BL containers. In that case, the solution height could triple for a hood with three filtration workstations to 0.84 cm. A 0.84 cm solution slab is well below the minimum 1 in. water-reflected subcritical slab thickness of roughly 76 mm (3 in.) from Figure 2.4 of TID-7016 [7].

The spill may flow between other containers present in the hood including the feed unit and pan. The pan is limited to 2 in. in height, does not contain solution, and is not as reactive as the depth of solution in the spill. The transformation of solution from a H/D~1 cylinder to a 3540 in^2 slab makes the BL configuration further subcritical due to the high neutron loss from a slab geometry. As a final argument, critical experiments reported in Table 51 of LA-10860 [6] and HEU-SOL-THERM-045 [10] of a solution slab below a solution cylinder show this upset condition is substantially subcritical. The critical configuration consists of 93.2% enriched uranyl nitrate solution at a concentration of 525 gU/L. The solution fills both a 120.7 cm × 120.7 cm × 8.9 cm (129-L volume), 0.64-cm thick stainless steel box that is concrete-reflected on its bottom, and an unreflected 9.21-in. diameter by 43.7-in. tall, 0.308-cm thick stainless steel cylinder (47-L volume). Both critical volumes vastly exceed that of the feed can or beaker and the spilled solution slab and the depth of the slab exceeds the 3-in. maximum depth maintained in the hood by the drain holes. Thus, either workstation with a solution spill is adequately subcritical.

Also, if there is a spill inside the hood, solution will not enter the hood exhaust because the bottoms of the filters are at least 9.5 in. above the hood floor. A spill could not accumulate to a 9.5 in. depth due to limited container volumes (discussed above) and hood drain holes that limit solution depth to 3 in.

5.3.5.2 Spill Outside the Hoods

Solution may spill on the facility floor as solution transfers occur outside the edge of the hood but within the boundary of the process. These transfers include pouring solution from a 4-L Erlenmeyer flask into a safe bottle, sampling a safe bottle, or draining leachate columns to a safe bottle. The BL process is located in an area where large geometries are not allowed and the floor is large and flat such that a solution spill will slab out in a fairly even layer. Due to the limited volume of the 4-L Erlenmeyer flask, drain holes in equipment, and the exclusion of large geometry containers in the area, the loss of control of another parameter must arise before it is possible to spill solution outside the hood into a non-favorable geometry. The solution likely will be spilled to the floor in a localized area, resulting in a slab configuration.

If a glass leachate column or wet vacuum trap breaks, there is the possibility of spilling a non-favorable volume of solution from a leachate column. There are wire shields that surround the leachate columns and wet vacuum traps to reduce the chance of breakage but these shields are required to not impede solution flow (drainage) in the event of a solution leak or failure. As a result, the solution will flow from the column or trap to the facility floor and form a slab geometry due to the large surface area of the BL area floor. Because there is no large geometry equipment in the area, solution cannot accidentally flow from a column or trap into a non-favorable geometry.

The subcritical limit for a spill on a concrete floor can be derived by averaging the limits for full reflection by concrete and for reflection by 1 in. of water. This approach is described on Page 108 of TID-7016 [7]. From Figure 2.4 of TID-7016, the subcritical thickness limit for an infinite slab of 500 g-^{235}U/L U(100)O_2F_2 solution with full water reflection is 4.2 cm. According to Section 3.16, the thick water reflector limit for slabs should be multiplied by the factor $0.44\rho^{-0.155}$ to obtain a limit for closely fitting concrete with areal density greater than 230 kg/m^2. In this factor, ρ is the fissile material concentration in g/cm^3. Therefore, for 500 g-^{235}U/L (0.5 g-^{235}U/cm^3) solution, the factor is 0.49, and the subcritical thickness limit for full concrete reflection is (4.2 cm)(0.49) = 2.06 cm. Figure 2.4 also gives a subcritical thickness limit of 8.2 cm for an infinite slab of 500 g-^{235}U/L U(100)O_2F_2 solution with 1 in. water reflection. Averaging the limits for full concrete reflection and 1 in. water reflection gives a subcritical thickness limit of 5.13 cm, or 2.02 in. The condition of the stainless steel floor and berms installed at the exits of Room X retain solution to a maximum depth of 1.59 in. Thus, a spill of fissile solution outside of the hoods will not result in a criticality.

5.3.6 Uranyl Nitrate Solution Spills into Feed Unit

Since the feed unit is only permitted in the dissolution workstation and the 4-L Erlenmeyer flask is only permitted in the filtering workstation, only the 4-L dissolver beaker could be spilled into the feed unit during equipment movement. This analysis bounds a spill in a hood where any of the solution enters the feed unit. If the feed can were filled with solution as analyzed, the depth of solution from the spill on the hood floor would be negligible. Also, the addition of the solution to a compact cylinder which already contains fissile material is much more reactive than a thin layer of solution on the floor due to the high leakage from the slab spill geometry.

The addition of fissile solution to a feed unit is bounded by either 1) optimum concentration fissile solution or 2) a single U-metal sphere in uranyl nitrate solution. If there is excess acid, the U metal or oxide in the feed unit will be dissolved into uranyl nitrate solution and the former condition will apply. If the fissile material is not dissolved, a slurry of undissolved uranium solids in saturated or supersaturated uranium solution will form. The most reactive configuration for modeling a slurry is undissolved uranium metal or high g U/g material as a single solid uranium metal body of low neutron leakage in an optimum concentration solution. Reference 11 concluded that the maximum reactivity for a mixture of U metal in a fissile solution is equal to that of a U metal sphere in a 300 gU/L metal-water mixture. Two calculations starting from the infinite workstation configuration with a beaker and a feed can shown previously in Figure 6 were performed to address these two scenarios. First, a green salt can filled with 350 gU/L uranyl nitrate solution was modeled as the feed can in case *2bgs350* with a result of 0.8331 ± 0.0011. Second, a hospital can containing a 10 kg-U metal sphere filled with a 300 gU/L metal-water mixture around the sphere was modeled as the feed can. This case, *2b10ms3mw*, had a result of 0.9512 ± 0.0010 for a $k_{eff} + 2\sigma$ value of 0.9532 which remains below the USL of 0.957. Filling the can with a U metal-water mixture is highly conservative for the BL operation that uses nitric acid. To quantify this conservatism, the hospital can was filled with 350 gU/L uranyl nitrate solution around the 10 kg sphere and k_{eff} was 1.5% lower at 0.9352 ± 0.0011 (case *2b10ms350*).

A 4-L uranyl nitrate solution spill into a plastic bag with contaminated combustibles is also considered. If optimum concentration solution for minimum volume (~500 gU/L) were to enter the plastic bag being used for feed material, the solution is not expected to collect to a depth of more than 3 in. due to the requirement that the corners of the plastic bags in a hood be snipped and that drain holes be present in the hood. This solution depth is subcritical with the nominal reflection afforded by the hood floor per Figure 2.4 of TID-7016. Any solution that leaves the plastic bag through these snipped holes will follow the pathway of the solution spill described in Contingency 5.3.5. Even if the corners of the bag are not snipped, the spill will not result in a criticality accident. Plastic bags are limited to dry or damp combustibles containing up to 350 g-^{235}U. Liquids are not allowed in the plastic bag so the liquid volume in the bag is 4 L. (The volume of contaminated combustibles is larger but the U density is low such that the use of a 4-L volume is appropriate.) From Figure 2.2 of TID-7016, the concentration of uranium must be 7 kg-U/L for the subcritical volume to be 4 L or less with nominal reflection. This would require 28 kg-U in the bag, which is not credible from the combination of 350 g-^{235}U in the bag and dissolution beaker solution, which is not expected to contain more than a few kg-U even if the solution is supersaturated. Note: Since bags of contaminated combustibles are bounded by feed cans, they will not be explicitly evaluated again in the analysis.

5.3.7 Excess Uranium in 4-L Dissolution Beaker

This contingency could result from supersaturation of the solution in the beaker, continuing to add uranium to saturated solution in the beaker or having weak nitric acid. The dissolution path that feed materials take is dependent on the form, the nature of the process, and experience of operators in adding the appropriate reagents. For many uranium forms (e.g., metal chips and fines and relatively pure oxides), the mass of solid uranium is precisely known as is its dissolution behavior such that the amount of uranium to be added in order to form a saturated solution is known prior to the dissolution of any uranium. For these forms, it is unlikely that a meaningful excess of uranium will be added to the 4-L dissolver beaker. The mass of uranium and the uranium density in roughing filters and contaminated combustibles is very low such that it is also unlikely that excess uranium will be added when dissolving these feed materials. The addition of 10 kg (an entire feed can) to a beaker containing optimum concentration solution is evaluated. This extent of overload is unlikely as normally approximately 1 kg of U can be fully dissolved in a beaker.

The solubility of many solids increases at higher temperatures (i.e., hot plate heating), and a solution that contains higher than saturated concentrations of solute can form. As the supersaturated solution cools, solid uranyl nitrate hexahydrate ($UO_2(NO_3)_2 \cdot 6H_2O$) crystals precipitate out of solution causing the solution to settle to a saturated state. These crystals will eventually settle out of the solution and collect in the bottom of the dissolver beaker in a similar fashion as undissolved uranium.

If uranium solids are added to water or 30% nitric acid that has already reached the saturation point, the solids may either become temporarily suspended in the solution (e.g., oxide powders) or will settle to the bottom of the saturated solution (e.g., metal chips). These solids are eventually filtered out in the Buchner funnel/filter combination, so the 4-L dissolver beaker is the only piece of equipment where supersaturation or suspension will arise.

Reference 11 concluded that the reactivity for a mixture of U metal in a fissile solution, such as the layer of precipitate in the bottom of the beaker, is maximized when modeled as a U metal sphere in a 300 gU/L metal-water mixture. Thus, the feed can in the infinite workstation array model shown previously in Figure 6 was modeled as a hospital can with a 10 kg-U metal sphere centered in the can and the remainder filled with 300 gU/L U metal-water solution. The total U content in the can was 11.2 kg. As discussed in Section 5.3.6, this scenario remains subcritical.

5.3.8 Pans on Shelves are Overfilled or Stacked Such that Fissile Depth Exceeds 2 Inches

This upset condition considers the depth of solids on the pan shelves exceeding 2 in. because either 1) a pan is overfilled and solid fissile material exceeds the depth of the pan or 2) pans are stacked. This contingency is unlikely because pans are never stacked in the facility and the shelf capacity is not likely to be exceeded such that an operator would attempt to stack the pans because the amount of solids generated is small (one pan would hold the solids from tens of batches and the pans are sent to Furnace A for disposition). Also, even if the pans are stacked, the solids depth may not exceed 2 in. if each pan is not full.

In the back of each hood, there is one continuous shelf for pans that is approximately 10-in. wide, 148.125-in. long, and at least 23.5 in. above the hood floor. Spacing is not required between pans on the shelves. Spacing between pans and process equipment is provided by the height of the shelf above the hood floor and location of the shelves relative to peripheral, fixed uranium-bearing equipment. However, process containers may be lifted during movements such that stacked pans on the shelves may interact with a passing pan, feed unit, 4-L dissolver beaker, or 4-L Erlenmeyer flask. CSE-CONT restricts pan loadings to wet salvage, solutions, sludge, slurries, and residues containing no UO_2 or U metal. These materials may be loaded until the pan is volumetrically full. The BL filtering operation does not generate UO_2 solids, but may generate U metal. Noticeable metal pieces are returned to the 4-L dissolver beaker for further dissolution.

Figure 84 of TID-7028 [8] gives critical data for a slab of $U(93.2)O_2F_2$ solution interacting (side-by-side) with a cylinder. With the slab and cylinder in contact with one another, the critical height of solution in each item is 37 cm. The uranium concentration of solution in the critical experiment is 77.9 g/L and the H/U ratio is 331, which is near optimal based on the calculations in Section 5.2.2.2. The slab and cylinder are not reflected other than the aluminum vessels they are contained in, which is similar to the reflection on the pan shelf. The cylinder is 9.88 in. in diameter, which is significantly larger than any process container in the BL process. The experimental slab width is 15.1 cm (5.94 in.) and the length is 121 cm (47.63 in.). The 37-cm (14.5-in.) solution depth in the slab is seven times that of a pan but the pans are wider than the experimental slab. Because a cuboid having sides equal in length is more reactive than a “flat” slab from both a single unit standpoint and an interaction standpoint, the aforementioned critical data can conservatively be extended to the full shelf length using conservation of volume. The slab volume in the experiment is 67.6 L. Eight pans on a 148.125-in. long pan shelf form a $6 \times 1 \times 1$ layer and the over-stack condition consists of a $2 \times 1 \times 1$ layer of pans stacked on top.

The total solution volume in the eight full pans is 56.6 L. Thus the critical experiment adequately bounds the pan shelf with two pans accidental stacked and a BL process container of solution in close proximity and the upset condition will remain subcritical. Thus, the loss of control of another controlled parameter in addition to interaction must occur before a criticality accident is possible.

5.3.9 Container Other Than a Pan Placed on Shelf

An administrative control requires that the pan shelves in every hood be used only for pans. There are only three pieces of uranium-bearing equipment that could be placed on the pan shelf, besides pans. These are the 4-L dissolver beaker, the 4-L Erlenmeyer flask, and the feed unit. Because these containers are actively used during the BL process, it is unlikely that an operator would set one of the containers out of reach on the pan shelf. If one of these pieces of equipment were to be placed on the pan shelf, the basis for safety of this configuration is bounded by the analysis in Section 5.3.5.1 for a spill of uranyl nitrate solution on the hood floor.

A 2-in. solution spill amongst a beaker and wetted feed unit in each workstation is shown to be subcritical in Section 5.3.5.1. The 2-in. deep spill is equivalent to the depth of the pans on the shelf and the hood floor area is larger than the area of the pan shelf. The feed unit and beaker are set into the solution which bounds a feed unit or beaker placed on the shelf next to the pans. Thus, a criticality accident will not occur if a container other than a pan is set on the pan shelf.

5.3.10 Fire with Uranium Metal Chips or Fines Occurs

Small pieces of uranium metal, such as chips or fines, are pyrophoric and can burn in air. This material is kept in liquid to prevent this type of fire. Even as chips and fines are filtered, some residual liquid remains on the small metal pieces due to surface tension. Thus, a chip fire is unlikely.

U metal fires are extinguished with graphite powder often referred to as coke. Cans of coke are stored under the BL hoods for easy access if a fire occurs. The operator pours the coke on the chips which limits the air and the fire is extinguished. This subsection evaluates the addition of the graphite powder to the U metal. Fire sprinkler activation is not expected if the operator uses the coke in a timely manner but sprinkler activation is evaluated in Section 5.3.4.

Subcritical data from Table 11 of LA-12808 for U(93.5) metal-water-carbon systems is referenced to demonstrate the effect of carbon on the U metal chip fire. The data shows that for an H/X=0, the minimum subcritical mass over the C/U range of 0 to 1000 is 14.4 kg-U with full water reflection. This minimum mass occurs at a C/U ratio of 1000 in a sphere with a volume of 390 L. From Table 28 of LA-10860-MS [12], graphite lowers the critical mass below that of a water reflected sphere but only as the reflector thickness approaches infinity. Graphite powder used to extinguish fires is of low density and is stored in a hospital can. Thus there is insufficient graphite available to produce the infinitely reflected 390 L sphere and the subcritical mass will be much greater than 14.4 kg-U. Hence, the use of graphite to extinguish a fire is not a criticality safety concern.

5.3.11 Seismic or Other Natural Phenomena Hazard Event Occurs

The BL hoods are seismically qualified such that the floor of the hood will remain flat during a seismic event and the drain holes will continue to limit the liquid accumulations to a maximum 3-in. depth. An earthquake could cause the breakage or spillage of the glass beakers and flasks in the hoods. As discussed in Section 5.3.5.1, the maximum solution height from spillage of the containers in three filtration workstations is limited to 0.84 cm. A 0.84-cm solution slab is well below the minimum 1-in. water-reflected subcritical slab thickness of roughly 76 mm (3 in.) from Figure 2.4 of TID-7016 [7]. Sprinkler piping may also be breached during a seismic event although it is expected that the sprinkler piping will breach upstream of Room X such that there will not be significant amounts of water in the line. Regardless, the hood cover is expected to remain in place to shed the water. If the water does enter the hoods, it will dilute any fissile solution on the hood floor and that solution would flow out the drain holes before a critical depth is achieved. The glass leachate columns may break and the safe bottle tip over spilling their contents onto the floor. The floor of Room X has also been shown to remain flat during a design basis seismic event such that a criticality accident will not occur. Room X has a large floor area for the solution to spread out in a subcritical slab depth and berms at the entrances to ensure a subcritical slab depth is maintained as discussed in Section 5.3.5.2. Thus, a criticality accident will not result from a seismic event. The facility has also been shown to withstand other natural phenomena events that stress the structure including credible explosions, lightning, roof ponding, etc. Flooding of the facility is also not credible due to its elevation. Fire sprinklers are installed and have been shown to control a fire before the damage results in a loss of criticality controls. The effects of the sprinkler water were evaluated in Section 5.3.4. Thus, a criticality accident resulting from a natural phenomena event is not credible.

5.4 <u>Conclusions</u>

The safety of the BL process hinges on the correct selection of process equipment. Specifically, it is important that the operation is limited to the fewest pieces of small volume equipment needed to carry out the process. The BL process has been evaluated under both normal and credible abnormal conditions and shown to remain subcritical. In addition, abnormal conditions satisfy the Double Contingency Principle or have been determined not to be credible such that an exception to DOE Order 420.1B is not required for this process.

6.0 CREDITED CONTROLS AND ASSUMPTIONS

6.1 <u>Passive Design Features</u>

The following NCS passive design features shall be implemented and maintained through the application of a Configuration Management Program, as appropriate, to ensure that the features function as stated.

6.1.1 The following equipment/containers shall have dimensions or volume not exceeding the given value(s):

- Leachate columns A and B shall have a maximum inner diameter of 6.186 inches, AND
- Wet vacuum trap shall have a maximum outer diameter of 5.6 inches, AND
- Erlenmeyer flask volume shall not exceed 4.411 liters.

These passive design features limit the volume and geometry of equipment/containers to the values analyzed. Note that geometry and volume limits of the other site-wide containers as given in Table 2 are listed as passive design features in CSE-CONT. Note that Erlenmeyer flasks with a volume greater than 4.411 liters are not used in any processes within the facility and the procurement specification for the flasks limits the volume to 4.411 liters such that flasks with a greater volume are not available.

6.1.2 The Buchner funnel used in the process shall not be capable to retaining liquid when set on the hood floor.

This passive design features ensures that the funnel will not retain liquid if set on the hood floor. The design of the open bottom of the funnel does not allow it to sit upright sealed with the floor. Note that other Buchner funnels are not used in any processes within the facility and the procurement specification for the funnels ensures that this requirement is met.

6.1.3 Any shields around traps or columns shall not impede liquid draining in the event a trap or column leaks or breaks.

This passive design feature limits the geometry of solution in the event of a trap or column failure.

6.1.4 A maximum of one safe bottle holder shall be positioned in front of each Beaker Leaching hood.

This passive design feature provides interaction control between safe bottles and between a safe bottle and equipment in the hoods. The safe bottle holder provides a fixed position for the safe bottle.

6.1.5 The positions of Leachate Columns A and B, the wet vacuum trap and the safe bottle staging area on the end of Hood A shall be as shown on Drawings X-2.

This passive design feature provides interaction control between fixed process equipment external to the hoods and external process equipment and equipment in the hoods.

6.1.6 Width of dividers between workstations and the edge-to-edge spacing between hoods shall be a minimum of 5.5 inches. Workstations shall be a minimum of 3 feet 6 inches wide to the center of the divider. The pan shelf shall be a minimum of 23.5 inches above the floor.

This passive design feature controls interaction between containers and equipment in adjacent workstations and on the pan shelf.

6.1.7 The floor of the Beaker Leaching hoods shall be a minimum of 26 inches above the concrete floor and distance of room walls to hood walls shall be a minimum of 12 inches.

This passive design feature ensures the concrete floor and walls are sufficiently far away that the reflection of containers in the hoods can be evaluated using 1-inch thick water or the actual hood floor material and thickness.

6.1.8 The floor of the Beaker Leaching hoods shall remain flat following a design basis seismic event such that liquids could not accumulate to a depth greater than 3 inches.

This passive design feature ensures that a subcritical configuration is maintained in the hoods following a seismic event.

6.1.9 The hood shall be equipped with drainage features that prevent the accumulation of liquid to a depth greater than 3 inches.

This passive design feature provides geometry control for solution spills in hoods or liquid ingress into hoods.

6.1.10 The bottoms of the hood exhaust filters shall be a minimum of 9.5 inches above the floor of the hood.

This passive design feature prevents solution from entering the hood exhaust filters and Stack 99 exhaust system in the event of a solution spill. This control is credited in CSE-S99.

6.1.11 The condition of the stainless steel floor liner and berms at the exits of Room X shall restrict the depth of a solution spill to a maximum of 2 inches, even following a design basis seismic event.

This passive design feature ensures that solution that may spill from the hoods, columns, trap or safe bottles will remain in a subcritical slab configuration.

6.2 Active Design Features

There are no active design features in the BL process.

6.3 Administratively Controlled Limits and Requirements

The following NCS limits and requirements shall be implemented through the application of operating procedures and/or surveillance program, as appropriate.

6.3.1 Each Beaker Leaching Dissolution Workstation shall be limited to the following containers:

- One feed unit,
  - A hospital can or green salt can loaded with up to 20 kg net weight UO_3 or U_3O_8, OR
  - A hospital can loaded with up to 5 kg net weight dry U metal or 3 kg net weight wet U metal as U metal chips, turnings, and fines, OR
  - A modified hospital can loaded with up to 10 kgU as U metal chips, turnings, fines, sludge, scrap, and clinkers, OR
  - A large or small plastic bag of combustibles with up to 350 g-^{235}U, OR
  - Roughing filters from a Beaker Leaching hood,
- One 4-liter beaker for dissolution,
- One “clean” 4-liter beaker for nitric acid or water, AND
- One non-shelved pan for sorting feed unit materials only.

This requirement provides volume control by limiting the number and volume of containers within a Dissolution Workstation. This requirement also provides feed material form and mass control. Note that container dimensions are restricted in CSE-CONT.

6.3.2 Each Beaker Leaching Filtration Workstation shall be limited to the following containers:

- One 4-liter dissolver beaker from the Dissolution Workstation,
- One 4-liter Erlenmeyer flask,
- One Buchner funnel and filter media,
- One non-shelved pan for filtered solids only, AND
- One small sample bottle.

This requirement provides volume control by limiting the number and volume of containers within a Filtration Workstation.

6.3.3 Pans shall not be filled above their rims and shall not be stacked.

This requirement provides geometry control by limiting the height of material in pans, which are unlimited in number on the shelf.

6.3.4 Hood shelves shall only be used for pans.

This requirement provides interaction control by limiting hood shelves to pans.

6.3.5 The corners of plastic bags shall be cut to a nominally 2-inch or greater length prior to placement in a hood.

This requirement provides geometry control during the upset of a spill into a plastic bag.

6.3.6 Hood drains shall be inspected before fissile material is brought into the hood to ensure that they are free from blockage.

This surveillance requirement is necessary to ensure that drain holes are able to perform as intended.

6.3.7 The floor of the exhaust plenums at the back of hoods A and B shall be inspected semiannually and cleaned out if visible accumulation is found.

This requirement provides defense-in-depth to prevent gradual accumulation of uranium in the exhaust plenum.

6.4 Assumptions

There are no assumptions in this evaluation of the BL process.

7.0 REFERENCES

1. *Beaker Leaching Process Description*, facility specific reference.

2. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, ORNL/TM-2005/39, Version 5, Vols. I-III, April 2005.

3. Facility specific KENO-V.a validation.

4. Facility specific calculation reference.

5. *American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, ANSI/ANS-8.1-1998, American National Standards Institute Inc., September 9, 1998.

6. H.C. Paxton and N.L. Pruvost, *Critical Dimensions of Systems Containing 235U, 239Pu, and 233U*, LA-10860-MS, Los Alamos National Laboratory, July 1987.

7. J.T. Thomas, *Nuclear Safety Guide*, TID-7016, Rev. 2, ORNL/NUREG/CSD-6, Union Carbide Corporation, June 1978.

8. H.C. Paxton, et. al., *Critical Dimensions of Systems Containing 235U, 239Pu, and 233U* , TID-7028, Los Alamos National Laboratory, June 1964.

9. Facility specific reference on drainage capacity of hoods.

10. "Slab-Cylinder Systems of Enriched Uranium Solutions", HEU-SOL-THERM-045, NEA/NSC/DOC/(95)03/II, Volume II, *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, Nuclear Energy Agency, Organization for Economic Co-operation and Development.

11. D.C. Hunt and R.E. Rothe, "A Criticality Study of Fissile-Metal and Fissile-Solution Combinations," *Nuclear Science and Engineering*, **53**, pp 79-92, 1974.

12. H.C. Paxton and N.L. Pruvost, *Critical Dimensions of Systems Containing* ^{235}U, ^{239}Pu *and* ^{233}U*, 1986 Revision,* LA-10860-MS, Los Alamos National Laboratory, Los Alamos, NM, July 1987.

APPENDIX A. WHAT-IF TABLE

No.	What-If	Causes	Consequences	Screening Results	Justification	Carries Forward?
Process Zone 1: Material Transfer into and out of the Hoods						
1.1	What if excess feed units are transferred into the hood?	• Operator error	• Excess mass in workstation	• Additional analysis required		Yes Sec 5.3.1
1.2	What if feed can contains excess mass?	• Operator error	• Excess mass in workstation	• Additional analysis required		Yes Sec 5.3.3
1.3	What if the wrong type of feed unit is brought into the hood?	• Operator error	• Excess mass in workstation • Excess volume in workstation	• Worst case evaluated under normal conditions	• No approved containers with higher U mass limits • Hospital can has largest volume of containers approved for U metal • Green salt can has largest volume of containers approved for oxide	No
1.4	What if feed unit contains excess moderation?	• Operator error when can was loaded • Legacy issue	• Excess moderation	• Additional analysis required		Yes Sec 5.3.2
1.5	What if excess container brought up against hoods?	• Operator error when transporting containers outside BL process	• Excess mass near hoods • Interaction with BL containers	• Additional analysis required		Yes Sec 5.3.1
1.6	What if a container other than a pan is placed on hood shelf?	• Operator error	• Interaction	• Additional analysis required		Yes Sec 5.3.9

No.	What-If	Causes	Consequences	Screening Results	Justification	Carries Forward?
Process Zone 2: Dissolution Workstation						
2.1	What if all fissile material in the beaker does not dissolve?	• Operator error • Error in acid composition	• U metal or oxide in beaker of saturated fissile solution • Solids precipitate as supersaturated solution cools	• Additional analysis required		Yes Sec 5.3.7
2.2	What if excess U added to dissolver beaker?	• Operator error	• Saturation limit exceeded such that U metal or oxide in beaker of saturated fissile solution	• Additional analysis required		Yes Sec 5.3.7
2.3	What if feed can spills?	• Operator error	• Dry fissile material or wet U metal on hood floor	• Spill results in less reactive configuration	• Spill of dry material will disperse it into a less reactive shape than it was in the container • Spill of moderated metal will be less reactive as moderating liquid will slab out on hood floor creating a less reactive configuration	No
2.3	What if dissolver beaker overflows or spills?	• Vigorous reactions cause bubbling or splattering of solution • Operator error	• Fissile solution under and around fissile containers or outside hood • Fissile solution added to feed unit	• Additional analysis required		Yes Sec 5.3.5 and 5.3.6

No.	What-If	Causes	Consequences	Screening Results	Justification	Carries Forward?
2.4	What if fissile solution backflows into reagent supply?	• None	• Fissile material in nonfavorable geometry reagent systems	• Not credible	• Reagent flows out of flexible tubing when valve is open. No credible means to backflow • Valves are above the drain holes such that fissile solution is not against the valve • No credible means of siphoning into the liquid lines	No
2.5	What if flask or funnel brought into dissolution workstation?	• Operator error	• Excess volume in workstation	• Additional analysis required		Yes Sec 5.3.1
2.6	What if fissile material placed in beaker of clean reagent?	• Operator error	• Excess volume in workstation	• Additional analysis required		Yes Sec 5.3.1
2.7	What if reagent is poured directly into feed can?	• Operator error	• Excess moderation of feed material	• Additional analysis required		Yes Sec 5.3.2
2.8	What if two pans are on the floor of the dissolution workstation?	• Operator error	• Excess volume in workstation	• Additional analysis required		Yes Sec 5.3.1
2.9	What if dissolution and filtration performed at the same workstation?	• Operator error	• Excess volume in workstation	• Additional analysis required		Yes Sec 5.3.1
2.10	What if a fire, including sprinkler activation, occurs in the area?	• Fire occurs	• Sprinkler activation in room • Coke used on U metal fire • Water entry into open face hoods	• Additional analysis required for sprinkler activation and use of coke		Yes Sec 5.3.4 and 5.3.10
2.11	What if an earthquake or other natural phenomena hazard event occurs?	• Natural phenomena event occurs	• Hood structural failure • Breach of sprinkler piping	• Additional analysis required		Yes Sec 5.3.11

No.	What-If	Causes	Consequences	Screening Results	Justification	Carries Forward?
Process Zone 3: Filtration Workstation						
3.1	What if feed unit is brought into filtration workstation?	• Operator error	• Excess volume in workstation	Additional analysis required		Yes Sec 5.3.1
3.2	What if excess beaker or flask brought into filtration workstation?	• Operator error	• Excess volume in workstation	Additional analysis required		Yes Sec 5.3.1
3.3	What if two pans are on the floor of the filtration workstation?	• Operator error	• Excess volume in workstation	• Additional analysis required		Yes Sec 5.3.1
3.4	What if dissolution and filtration performed at the same workstation?	• Operator error	• Excess volume in workstation	• Additional analysis required		Yes Sec 5.3.1
3.5	What if flask is overfilled and solution backs up into funnel?	• Operator error	• Spill of solution through flask overflow into hood	• Additional analysis required		Yes Sec5.3.5
3.6	What if pans are overfilled or stacked on the pan shelf?	• Operator error	• Fissile depth greater than analyzed in normal condition	• Additional analysis required		Yes Sec 5.3.8
3.7	What is a container other than a pan is set on the pan shelf?	• Operator error	• Fissile depth greater than analyzed in normal condition	• Additional analysis required		Yes Sec 5.3.9
3.8	What if a fire, including sprinkler activation, occurs in the area?	• Fire occurs	• Sprinkler activation in room • Coke used in hoods • Water entry into open face hoods	• Additional analysis required for sprinkler activation		Yes Sec 5.3.4
3.9	What if an earthquake or other natural phenomena hazard event occurs?	• Natural phenomena event occurs	• Building or hood structural failure • Breach of sprinkler piping	• Additional analysis required		Yes Sec 5.3.11

No.	What-If	Causes	Consequences	Screening Results	Justification	Carries Forward?
Process Zone 4: Solution Transfer by Pouring or Wet Vacuum (includes sampling)						
4.1	What if leachate column or wet vacuum trap leaks or breaks?	• Equipment failure • Operator error	• Spill of fissile solution on floor	• Additional analysis required		Yes Sec 5.3.5.2
4.2	What if fissile solution spills during transfer?	• Equipment failure • Operator error	• Fissile solution under and around fissile containers	• Additional analysis required		Yes Sec 5.3.5 and 5.3.6
4.3	What if reagents spill or supply lines leak?	• Operator error • Equipment failure	• Excess moderation/reflection	• Additional analysis required		Yes Sec5.3.4
4.4	What if an earthquake or other natural phenomena hazard event occurs?	• Natural phenomena event occurs	• Building or hood structural failure • Breach of glass columns	• Additional analysis required		Yes Sec 5.3.11

APPENDIX B. SAMPLE INPUT FILES

Case *4beaker300h* from Table 3

```
=csas25         parm=size=4000000
4 liter beaker model at H/D=1 steel floor & 1" h2o refl 2x2x1 array
238group        infhom
solnuo2(no3)2 1   300   0  1.0 293 92235 100 end
h2o             2  end
ss304           3  end
arbmpyrex       2.23 5 1 0 0 5000 3.7 8016 53.5 14000 37.7 11023 4.1
              13027 1.0 6 1.0 293 5010 0.0 5011 100 end
plexiglas       7 end
end comp
4 liter beaker model at H/D=1 steel floor & 1" h2o refl 2x2x1 array
read param  run=yes nub=yes gen=300 npg=5000 nsk=100 end param
read geom
unit 1
com="4-liter beaker"
cylinder        1 1        8.6      17.2    0
cuboid          0 1      4p8.6      17.2    0

global unit 2
com="2x2x1 array of beakers"
array 1 0 0 0
reflector 2 1 5r2.54 0 1
reflector 3 1 5r0 0.4763 1
end geom
read array
ara=1 nux=2 nuy=2 nuz=1 fill f1 end fill
end array
end data
end
```

Case *4base* from Table 3

```
=csas25         parm=size=4000000
4 4 liter beakers H/D=1 +pan+bottle Mirrored
'steel floor & 1" h2o refl
238group        infhom
solnuo2(no3)2 1   350   0  1.0 293 92235 100 end
h2o             2  end
ss304           3  end
end comp
4 4 liter beakers H/D=1 +pan+bottle Mirrored
read param  run=yes nub=yes gen=350 npg=5000 nsk=150 end param

read geom
unit 1
com="4-liter beaker"
cylinder        1 1    8.6    17.2    0
cuboid          0 1  4p8.6    17.2    0

unit 5
com="pan full of solution"
cuboid          1 1     33.02 0 22.86 0 5.08 0
```

```
unit 6
com="safe bottle"
cylinder      1 1     5.937    137.160   0
zhemicyl+x     2 1     8.477    139.7   0 chord 5.937

global unit 10
com="2x2x1 array of beakers with water reflection"
array 1 41.165 0 0
'gap to edge of pan
cuboid        0 1 75.565 0 57.261 0 17.2 0
hole          5   42.545 34.4 0
'nominal reflection around containers
reflector     2 1 3r2.54 0 2.54 0 1
'rest of workstation including divider
cuboid        0 1 78.105 -2.54 99.695 -6.985 72 0
'steel floor of hood
reflector     3 1  5r0 0.4763 1
cuboid        0 1 95 -2.54 99.695 -6.985 72 -68.263
'safe bottle next to hood
hole          6   84.042 8.6  -68.2625
end geom

read array
ara=1 nux=2 nuy=2 nuz=1 fill f1 end fill
end array

read bounds
yfc=mirror
end bounds
end data
end
```

Case *2box20gswet* from Section 5.3.2.1

```
=csas25        parm=size=4000000
4 liter beakers H/D=1 + 20kg GS can wet +pan+bottle Mirrored
'steel floor & 1" h2o refl
238group       infhom
solnuo2(no3)2 1   350   0  1.0 293 92235 100 end
h2o          2  end
ss304        3  end
'U3O8 at H/X=6.2
u-235        4 0 6.708E-03 end
h            4 0 4.159E-02 end
o            4 0 3.868E-02 end
end comp
4 4 liter beakers H/D=1 +pan+bottle Mirrored
read param  run=yes nub=yes gen=300 npg=5000 nsk=100 end param

read geom
unit 1
com="4-liter beaker"
cylinder      1 1    8.6    17.2    0
cuboid        0 1  4p8.6    32.385  0
```

```
unit 2
com="20kg wet U3O8 filling Green Salt Can"
cylinder       4 1    7.62   32.385  0 origin -0.98 0.98
cuboid         0 1  4p8.6    32.385  0

unit 5
com="pan full of solution"
cuboid         1 1     33.02 0 22.86 0 5.08 0

unit 6
com="safe bottle"
cylinder       1 1      5.937    137.160   0
zhemicyl+x      2 1      8.477     139.7   0 chord 5.937

global unit 10
com="2x1x1 array of beakers with water reflection"
array 1 41.165 0 0
'gap to edge of pan
cuboid         0 1 75.565 0 40.061 0 32.385 0
hole           5   42.545 17.2 0
'nominal reflection around containers
reflector      2 1 3r2.54 0 2.54 0 1
'rest of workstation including divider
cuboid         0 1 78.105 -2.54 99.695 -6.985 72 0
'steel floor of hood
reflector      3 1  5r0 0.4763 1
cuboid         0 1 95 -2.54 99.695 -6.985 72 -68.263
'safe bottle next to hood
hole           6   84.042 8.6  -68.2625
end geom

read array
ara=1 nux=2 nuy=1 nuz=1 fill 1 2 end fill
end array

read bounds
yfc=mirror
end bounds
end data
end
```

Case *2bm10water* from Section 5.3.4

```
=csas25         parm=size=4000000
1 4 liter beakers H/D=1+10kg wet can+pan+bottle Mirror 3" water
'steel floor & 1" h2o refl
238group        infhom
solnuo2(no3)2 1   350   0  1.0 293 92235 100 end
h2o            2  end
ss304          3  end
'metal-water mixture at H/X=10.7
u              4  den=18.81  0.114590 293 92235 100 end
h2o            4            0.885410 293 end
end comp
1 4 liter beakers H/D=1+10kg wet can+pan+bottle Mirror 3" water
read param  run=yes nub=yes gen=300 npg=5000 nsk=100 end param
```

```
read geom
unit 1
com="4-liter beaker with water up to 3 in"
cylinder     1 1   8.6   7.62   0 origin 0.3693 0.3693
cuboid       2 1  4p8.9694 7.62   0

unit 11
com="4-liter beaker above water"
cylinder     1 1   8.6   17.2   7.62 origin 0.3693 0.3693
cuboid       0 1  4p8.9694 18.398  7.62

unit 2
com="10 kg U water in Hospital Can with water up to 3in "
cylinder     4 1   8.9694 7.62  0
cuboid       2 1  4p8.9694 7.62  0

unit 12
com="10 kg U water in Hospital Can above water"
cylinder     4 1   8.9694 18.398  7.62
cuboid       0 1  4p8.9694 18.398  7.62

unit 5
com="pan full of solution"
cuboid       1 1    33.02 0 22.86 0 5.08 0

unit 6
com="safe bottle"
cylinder     1 1     5.937   137.160   0
zhemicyl+x     2 1     8.477    139.7   0 chord 5.937

unit 7
com="bottom half of array in 3 in water"
array 1 39.6874 0 0
'gap to edge of pan
cuboid       2 1 75.565 0 40.7991 0 7.62 0
hole       5   42.545 17.939 0
'nominal reflection around containers
reflector    2 1 3r2.54 0 0 0 1
'rest of workstation including divider
cuboid       2 1 78.105 -2.54 99.695 -6.985 7.62 0
'steel floor of hood
reflector    3 1  5r0 0.4763 1

unit 8
com="top half of array above water"
array 2 39.6874 0 7.62
'gap to edge of pan
cuboid       0 1 75.565 0 40.7991 0 18.398 7.62
'nominal reflection around containers
reflector    2 1 3r2.54 0 2.54 0 1
'rest of workstation including divider
cuboid       0 1 78.105 -2.54 99.695 -6.985 20.938 7.62

global unit 10
```

```
com="both halves of workstation"
array 3 -2.54 -6.985 0
cuboid         0 1 95 -2.54 99.695 -6.985 72 -68.263
'safe bottle next to hood
hole           6   84.042 8.6  -68.2625
end geom

read array
ara=1 nux=2 nuy=1 nuz=1 fill 1 2 end fill
ara=2 nux=2 nuy=1 nuz=1 fill 11 12 end fill
ara=3 nux=1 nuy=1 nuz=2 fill 7 8 end fill
end array

read bounds
yfc=mirror
end bounds
end data
end
```

Case *2b10ms3mw* from Section 5.3.6

```
=csas25        parm=size=4000000
1 4 liter beakers H/D=1+ 1 10kg & 300gU/lmet-H2O +pan+bottle Mirrored
'steel floor & 1" h2o refl
238group       infhom
solnuo2(no3)2 1   350   0  1.0 293 92235 100 end
h2o            2  end
ss304          3  end
u              4  den=18.81  1.0 293 92235 100 end
'Metal-water mixture at 300 gU/l
u              5  den=18.81  0.015938 293 92235 100 end
h2o            5            0.984062 293 end
end comp
1 4 liter beakers H/D=1+ 1 10kg & 300gU/lmet-H2O +pan+bottle Mirrored
read param  run=yes nub=yes gen=300 npg=5000 nsk=100 end param

read geom
unit 1
com="4-liter beaker"
cylinder       1 1    8.6    17.2    0 origin 0.3693 0.3693
cuboid         0 1  4p8.9694 18.398  0

unit 2
com="10 kg U  in Hospital Can filled with soln"
sphere         4 1  5.025 origin -2.527 2.527 8.6
cylinder       5 1    8.9694 18.398  0
cuboid         0 1  4p8.9694 18.398  0

unit 5
com="pan full of solution"
cuboid         1 1     33.02 0 22.86 0 5.08 0

unit 6
com="safe bottle"
cylinder       1 1      5.937    137.160   0
zhemicyl+x      2 1      8.477    139.7   0 chord 5.937
```

```
global unit 10
com="2x1x1 array of beakers with water reflection"
array 1 39.6874 0 0
'gap to edge of pan
cuboid      0 1 75.565 0 40.7991 0 18.398 0
hole        5   42.545 17.939 0
'nominal reflection around containers
reflector   2 1 3r2.54 0 2.54 0 1
'rest of workstation including divider
cuboid      0 1 78.105 -2.54 99.695 -6.985 72 0
'steel floor of hood
reflector   3 1  5r0 0.4763 1
cuboid      0 1 95 -2.54 99.695 -6.985 72 -68.263
'safe bottle next to hood
hole        6   84.042 8.6  -68.2625
end geom

read array
ara=1 nux=2 nuy=1 nuz=1 fill 1 2 end fill
end array

read bounds
yfc=mirror
end bounds
end data
end
```