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The Impact of Climatological Conditions on Low Enriched Uranium Loading Station Operations for the HEU Blend Down Project

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Keywords: HEU Blend Down, LEU, TVA, Weather Impact, and Heat Stress.

ABSTRACT

A computer model was developed using COREsim to perform a time motion study for the Low Enriched Uranium (LEU) Loading Station operations. The project is to blend Highly Enriched Uranium (HEU) with Natural Uranium (NU) to produce LEU to be shipped to Tennessee Valley Authority (TVA) for further processing.

To cope with a project cost reduction, the LEU Loading Station concept has changed from an enclosed building with air-conditioning to a partially enclosed building without air conditioning. The LEU Loading Station is within a radiological contaminated area; two pairs of coveralls and negative pressure respirator are required. As a result, inclement weather conditions, especially heat stress, will affect and impact the LEU loading operations.

The purposes of the study are to determine the climatological impacts on LEU Loading operations, resources required for committed throughputs, and to find out the optimum process pathways for multi crews working simultaneously in the space-limited LEU Loading Station.

INTRODUCTION

A LEU Loading simulation computer model was developed using software package COREsim (by Vitech Corp.) to functionally model and simulate the processes of the HEU Blend Down Project.

The highly Enriched Uranium (HEU) blend down process will blend HEU with Natural Uranium (NU) to produce Low Enriched Uranium (LEU) which will be shipped to the Tennessee Valley Authority (TVA) for further processing [Interagency Agreement]. Eventually, the fuel is to be used in a power plant for power generation.

HEU fuel (with an enrichment of up to 70wt% ^{235}U in uranium) is dissolved and purified in a facility inside SRS. The purified HEU solutions are transferred into tanks, sampled, and then transferred to a Hold Tank. From Hold Tank, the solution is fed as needed to a Blend Tank, where it is blended with natural uranium solution.

The NU (with an enrichment of up to 0.72wt% ^{235}U in uranium) solutions are received from a vendor trailer into tanks. From these tanks, the NU solution is fed as needed to the Blend Tank.

The HEU and NU solutions are mixed in the Blend Tank in the appropriate proportions to achieve about 4.95wt% enrichment, referred to as LEU. The product specification is for an enrichment range of 4.90wt% to 4.99wt%. Based on sample results, small amounts of NU solution or HEU solution are added to produce the desired enrichment. One or more Blend Tank samples are used to verify that the final blend meets the customer specifications.

Once sampling indicates an acceptable LEU product, the blended solution is sampled and transferred to LEU Transfer Tank. Transfer Tank solution will be sampled before sending the LEU to the shipping trailer by way of a Measuring Tank. Both the final Blend Tank sample, and the Transfer Tank sample, will be analyzed before the solution is transferred to the shipping trailer.

The shipping trailer holds nine LEU shipping containers, each with a volume of about 260 gallons, and a shipping capacity of about 230 gallons. The shipping containers are filled one at a time, with a Measuring Tank used to control the volume of solution transferred to a LEU shipping containers. The filling process starts with preparation of the container to receive the solution. The preparation involves:

- Removing the plug from the top of the container,
- Removing the flanged plate that covers the fill and vent lines and valves,
- Connecting the vent line hose to the vent connection in the top of the container,

- Opening the vent line valves,
- Verifying with a hand-held depth measurement device that the container is essentially empty,
- Connecting the fill line hose to the fill connection in the top of the container, and
- Opening the fill line valves.

Once the LEU shipping container is ready, the Loading Station operator activates permissive interlock to allow the filling of the container. Solution is then pumped from LEU Transfer Tank to the Measuring Tank until Measuring Tank is filled. Then the outlet line to the Loading Station is opened to allow the solution to gravity drain to the shipping container. The container is surveyed for contamination and decontaminated as necessary. Then the flanged plate and plug are replaced, closing the secondary containment.

Once the LEU shipping containers are filled and sealed, the tractor is connected to the trailer, and the truck dispatched to the vendor.

The required LEU process rate is given in Table 1.

Table 1. The LEU Process Rates

Process Rates	Required Throughput (gal/month)
Peak Monthly Process Rate	13,088

MODEL OBJECTIVES

The objectives of the model are to identify strengths and weaknesses in process, develop potential staffing profile, and to support design development.

The discrete event simulation model is to analyze the dynamic performance and behavior of systems, and perform a time-motion study that can enhance the understanding of the HEU Blend Down process. The simulation provides insight into utilization of resources and plant capacities. In addition, modified operating scenarios can be easily produced and analyzed to provide information on process pinch points and to support the planning and management decision making process.

The model will verify the required process throughput, the resources required for three different process rates, and the impact of batch size in the Blend Tank, and will evaluate the impact of different shift schedules on process rate.

CLIMATOLOGICAL IMPACT

Without air-conditioning, inclement climate conditions will affect and impact the LEU loading operations. One purpose of the report is to evaluate the impact of inclement weather on the LEU Loading operations.

The LEU Loading Station is in a clear span, partially enclosed and roofed outdoor structure with ridge vent. The dimensions of LEU Loading Station building are nominally 25 feet wide by 60 feet long, with a 22 feet eave height. Wall panels on the north and south sides are to be installed to allow a 3' high opening along the base of the wall, and a 4' high opening along the eave for ventilation. There is no insulation in the wall panels. Wall panels on the West Side are to be full-height, and have a nominally sized 3' x 7' personnel access opening centered in the wall. No door is required in this opening. The East Side of the building shall be open. The roof insulation has a minimum R-value of 19. There is no air conditioning inside the building. Cooling will be provided by natural convection through the opening at partial walls.

There are four types of inclement weather conditions to be evaluated:

- Heat Stress,
- Extremely High Wind condition,
- Wet, cold, and with High Wind,
- Low Temperature

Workday Loss in this report is defined as the accumulated work time loss during normal work schedule due to the inclement weather conditions.

The latter three of the four conditions listed above were evaluated with available meteorological data. Evaluation of heat stress for this facility required adaptation of an existing model used at SRS to calculate heat stress potential for outdoor work.

Heat Stress Algorithm for Partially Enclosed Structures

Wet Bulb Globe Temperature

The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLV) for heat exposure provide the basis for heat stress management at SRS [WSRC, 1995]. The heat exposure TLV's are based on observed values of wet bulb globe temperature (WBGT). The WBGT is defined as:

$$\text{WBGT (outdoor)} = 0.7T_n + 0.2T_g + 0.1T_a \quad (1)$$

$$\text{Or, WBGT (indoor)} = 0.7T_n + 0.3T_g \quad (2)$$

where T_n is a 'natural' (static) wet bulb temperature, T_g is a 'globe' temperature, and T_a is the ambient (dry bulb) temperature.

Unlike standard wet bulb temperature (Tw), which is typically used to quantify atmospheric moisture, 'natural' wet bulb provides a direct measure of the apparent temperature achieved by a moist, radiantly reflective body in equilibrium with the ambient environment. A natural wet bulb thermometer consists of a mercury thermometer covered with a wetted, white muslin wick and exposed to the atmosphere without ventilation or shielding, fully subject to gains and losses of heat through evaporation, solar radiation, and convection.

Similarly, T_g is used to approximate the temperature of a dry, radiantly absorptive body in the ambient environment. A globe thermometer typically consists of a thermally sensitive element placed at the center of a blackened, hollow copper sphere.

Neither T_n nor T_g represents perfectly the heat load on a clothed human body. Therefore, the WBGT heat stress 'model' is expressed as a weighted sum of these apparent temperatures. The respective weights are based on correlations with observed deep body temperature and other physiological responses to heat [ACGIH, 1995]. In practice, values of WBGT are used to determine one of six heat stress categories. Each category, in turn, defines a prescribed work/rest regimen for outdoor activities.

Portable, manually operated instruments are available to measure WBGT; however, routine measurements with such instruments are labor intensive and subject to operator error. Consequently, a computer algorithm was developed in 1996 which estimates WBGT using standard meteorological data. This algorithm has been linked to the SRS meteorological database to automatically calculate WBGT and post the results on an intranet web page (Hunter, 1999). In addition, this algorithm can be run with historical data sets to allow climatological characterizations of heat stress potential.

Description of the Existing WBGT Algorithm (Outdoor)

Meteorological monitoring at SRS is conducted from a network of nine 61-meter(m) towers. Eight of these towers are equipped to measure wind speed, wind direction, temperature, and dew point at 61m and temperature and dew point at 2m above ground level. The ninth tower, the Central Climatology tower, near the geographic center of the SRS, is equipped to measure wind speed, wind direction, temperature, and dew point at four levels (2m, 18m, 36m, and 61m), plus precipitation, pressure, solar radiation, and pan evaporation at ground level. All data are recorded as 15-minute averages and automatically archived in a relational database.

The two principal temperatures that comprise WBGT, natural wet bulb temperature, T_n, and globe temperature, T_g, are highly specialized quantities not typically included in conventional meteorological monitoring programs. The following sections describe the algorithms that are used to estimate T_n and T_g from these standard measurements [Hunter, 1999].

Natural Wet Bulb Temperature

The expression currently used to estimate T_n was developed from manual WBGT data collected on ten days during June and July of 1999. These days were selected to give a range of weather conditions that can be expected in the SRS region in summer. An analysis of variance was performed to determine the relationship between measured values of T_n and 15-minute average meteorological data from Central Climatology. As expected, nearly 70 percent of the variance in the difference between T_n and T_w was due to wind speed and solar radiation. Multiple linear regression on the data resulted in the following predictive expression for T_n:

$$T_n = T_w + 0.021S - 0.42u + 1.93 \qquad (3)$$

where S is solar irradiance (W/m^2) and u is wind speed (m/s).

The wet bulb temperature is calculated from the expression:

$$T_w = T_a - \{[0.034N - 0.00072N(N-1)]\,[T_a+T_d-2P+108]\}$$

Where T_d is the dew point temperature, P is pressure (inches Hg) and $N = (T_a - T_d)/10$.

All temperatures in equation 3 and 4 are in Fahrenheit. Estimates of T_n are calculated from these equations using measured values of S, u, T_d, T_a, and P.

Globe Temperature

Globe temperature, T_g, is calculated explicitly using the expression:

$$\underbrace{(1-\alpha_{sps})S[f_{db}s_{sp}+(1+\alpha_{es})f_{dif}]}_{[1]} + \underbrace{\varepsilon_a(1-\alpha_{spl})\sigma T_a^4}_{[2]} = \underbrace{\varepsilon\sigma T_g^4}_{[3]} + \underbrace{0.115u^{0.58}(T_g-T_a)}_{[4]} \qquad (5)$$

The two terms on the left side of Eq. (5) represent the sum of radiant energy absorbed by the globe in the visible spectrum (term [1]) and infrared spectrum (term [2]), respectively. Solar radiation, S, striking the earth's surface consists of direct beam (db) radiation from the sun and diffuse (dif) radiation reflected by clouds and other atmospheric constituents. For high solar angles (midday) and cloudless skies, approximately 75 percent of the total incoming solar energy consists of direct beam radiation and the remaining 25 percent diffuse radiation [Oke, 1978]. The contribution of diffuse radiation to the total solar load increases with increasing cloudiness and haze and with lower solar angles. Since summer afternoons at SRS are frequently hazy with some cloudiness, the average fractional contribution of direct beam radiation, f_{db}, and diffuse radiation, f_{dif}, are assigned values of 0.67 and 0.33, respectively.

Solar irradiance, S, is measured at Central Climatology by a radiometer that is level with respect to the horizontal plane (i.e. the earth's surface). The spatially averaged direct beam irradiance on any three dimensional object can be related to measured values of S by determining a shape factor, s, for the object. The shape factor for a sphere (globe) is defined as the ratio of the area of a shadow projected on the horizontal plane to the surface area of the sphere, or

$$s_{sp} = \pi r^2/[4\pi r^2 \cos(z)] = 1/[4 \cos (z)] \qquad (6)$$

where z is the solar angle to zenith.

Diffuse solar radiation is isotropic, that is, emitted (or received) equally in all directions. Therefore, the diffuse solar radiation measured by a radiometer is equal to that received by the upper hemisphere of the globe. The lower hemisphere of the globe also will receive short-wave radiation reflected from the ground and nearby low structures. The albedo, α_{es}, for grassy surfaces ranges from 0.15 to 0.25. A value of 0.2 was assumed for this calculation [Budyko, 1974].

The second term on the left of Eq. (5) is the long-wave (thermal) black-body radiation emitted by (received from) a moist, cloudless atmosphere of temperature T_a and thermal emissivity ε. Thermal emissivity, a function of atmospheric water vapor, is calculated from the empirical formula

$$\varepsilon_a = 0.575 e_a^{(1/7)} \qquad (7)$$

where e_a is atmospheric vapor pressure [Oke, 1978]. Real-time values of e_a are determined from the expression

$$e_a = (1.0007 + 0.00000346P) \exp \{[17.67T_d / (T_d + 243.5)] - [17.67T_a / (T_a + 243.5)]\} \{6.1121^* \exp [17.502T_a/(240.97 + T_a)]\} \qquad (8)$$

Temperatures in Eq. 8 are Celsius and pressure is in millibars. The Stefan-Boltzmann constant σ in Eq. (5) is equal to 5.67 X 10-8 ($Wm^{-2}K^{-4}$).

Imperfections in the black matte finish of the globe thermometer will cause small amounts of radiation striking the surface of the sphere to be reflected back to the atmosphere. Globe albedo for short and long wave radiation, α_{sps} and α_{spl}, respectively, were each assigned a value of 0.05 [Kuehn, 1970].

The two terms on the right side of Eq. (5) represent total radiant energy lost by the globe. The first term (term [3]) expresses long-wave black body radiation emitted from a globe at temperature T_g. The thermal emissivity, ε, for a globe of black matte finish was assigned a value of 0.95 [Kuehn, 1970]. The second term on the right (term [4]) is an empirical expression recommended by Kuehn (1970) for the net convective heat loss (or gain) from a sphere of temperature T_g (°C) immersed in air of temperature T_a (°C) moving at a speed u (m/hr).

Equations (6) - (8) are evaluated using real-time 15-minute averages of S, T_a, T_d, P, and u from Central Climatology. An iterative procedure is used to determine the value of T_g that satisfies the equilibrium condition.

Computed values of T_n and T_g are used with observed 15-minute averages of T_a to determine WBGT according to Eq. 1. Field tests of the alogrithm have shown that the estimates of T_n, T_g, and WBGT agree well with measure values [Hunter, 2000].

Modified WBGT Algorithm for Assessing Heat Stress Potential in LEU Loading Station

The WBGT algorithm described in the previous section is applicable to workers in the ambient environment. In a partially enclosed structure such as the LEU Loading Station, an individual will receive little or no direct sunlight, but may be exposed to radiant heat from the roof or side panels of the structure. Consequently, a modified form of the basic WBGT algorithm was developed which accounts for these changes in the overall heat energy balance.

The most significant modifications affect the calculation of T_g. Two calculations prior to final determination of T_g have been added:

Step 1: Estimate temperature for the outer surface of a 'flat' roof.

An estimate of the equilibrium temperature of the outer skin of a flat (or nearly flat) roof was based on a simple modification to equation 5 to account for a different geometry and surface emissivities. The term s_{sp} is set to a value of 1 since the irradiance on a flat roof (i.e. a surface nearly parallel to the horizontal plane of the earth) will be approximately equal to that measured by the pyranometer at Central Climatology.

Eq. (5) then becomes:

$$(1-\alpha_{rs})\, S\, (f_{db}+ f_{dif}) + \varepsilon_a(1-\alpha_{rl})\sigma T_a^4 = \varepsilon\sigma T_{roof}^4 + 0.115\, u^{0.58}(T_{roof}-T_a) \qquad (9)$$

Roof albedo will depend on the type of material, the finish (i.e. polished, painted), and wavelength of the incident radiation. The LEU will have a roof of sheet steel finished with light color oil paint. Albedos (α_{rs} and α_{rl} for solar and thermal wavelengths respectively) for this surface are estimated to be about 0.7 in the visible wavelengths and 0.25 in the infrared wavelengths [Iqbal, 1983]. Eq. 9 is solved iteratively and the resulting value for the outer roof skin temperature, T_{roof}, is applied in step 2.

Step 2: Estimate the equilibrium temperature of the inner roof surface (ceiling)

The LEU roof will be insulated to achieve a minimum thermal resistance per unit area, R, of 19 W/K-m^2. Heat energy transfer per unit area by conduction, Q (W/m^2), from the outer roof surface (warm) to the inner surface (cool) was estimated using the following simple steady state equation [Kreith, 1973]

$$Q = T_{roof}-T_a/R \qquad (10)$$

The final equilibrium temperature of the inner roof surface (T_{ceil}) will depend on the sources of radiant heat within the structure and the heat gained from conduction. Assuming no radiant sources other than the ambient air, T_{ceil} is determined by solving the expression

$$(1-\alpha_{cel})\sigma T_{ceil}^4 = Q + (1-\alpha_{cel})\sigma T_a^4 \qquad (11)$$

where α_{cel} in this calculation is the albedo of the ceiling to thermal wavelengths and assigned a value of 0.35 [Perry].

Step 3: Estimate Globe Temperature Inside the Covered Structure

Given T_{ceil}, an estimate of the globe temperature at ground-level inside the LEU Loading Station was determined from a modified form of Eq (5):

$$(1-\alpha_{sps})S(0.1(1+\alpha_{es})f_{dif}) + \varepsilon_a(1-\alpha_{spl})\sigma T_{ceil}^4 = \varepsilon\sigma T_g^4 + 0.115u_i^{0.58}(T_g-T_a) \qquad (12)$$

The applicability of this expression is based on an assumption that radiant heat from the ceiling is isotropic, i.e., the 'hot' ceiling is a sphere symmetric with respect to the globe thermometer. Generally, this assumption should be conservative since on average the sides of the structure will be cooler than the ceiling. A small contribution to T_g will come from diffuse sunlight through the open sides of structure. For this calculation, the value of S was assumed to be one-tenth the value of the diffuse component of ambient solar irradiance. In addition, wind speed inside the structure, u_i, was assumed to be 20 percent of the ambient wind speed

The natural wet bulb temperature, T_n , within the LEU Loading Station was based on eq. 3 with two adjustments: (1) the solar irradiance, S, inside the structure was assumed to be 10 percent of the measured ambient value and (2), the wind speed, u, was assumed to be 20 percent of the measured ambient value.

Final calculation of WBGT inside the LEU Loading Station was based on Eq. (2).

Evaluation

Results from a brief informal field test and a review of WBGT data for May-September 1999 were used to demonstrate the adequacy of the modified algorithm for the intended purpose. The field test was conducted in and around 643-43E, a structure very similar in design to the LEU Loading Station, on 24-October-2001. Weather conditions during the time of the test were partly cloudy with unusually warm temperatures, light wind, and a relative humidity around 50 percent. A manual WBGT instrument was used to measure T_a, T_n, T_g, and WBGT over a 20-minute interval in the early afternoon. These measurements are summarized in Table 2. This table also shows (in parenthesis) calculated values for T_n, T_g, and

WBGT using the modified algorithm described in the previous section of this report. For this test period, calculated values show good agreement with the measurements.

Table 2 – Manual WBGT Data Collected at 643-43E, 24-October-2001

Inside 643-43E

Time	T_a	T_n	T_g	WBGT
1341	85.5	72.0	85.9	76.2
1343	85.9	72.2	86.6	76.5
1345	86.1 (85.2)	72.2 (72.5)	86.8 (87.5)	76.6 (77.2)
1347	85.7	72.2	86.6	76.5
1349	85.4	72.2	86.2	76.2
1351	85.2	72.2	85.7	76.2
1356	83.4	71.3	83.4	74.9
1400	83.5 (85.3)	71.6 (72.8)	83.1 (88.2)	75.0 (77.4)
Outdoor				
1408	87.0 (86.0)	74.1 (74.5)	109 (105)	85.7 (82.0)

In addition, a set of measurements was collected in a well-exposed area outside of 643-43E. These data illustrate the significant effect of solar radiation on T_g and on the final WBGT result.

Summary of Weather Impact

In general, the data demonstrate that the shade provided by a partially enclosed structure gives a significant reduction in WBGT, as long as the structure utilizes materials with low thermal emissivities and/or high thermal resistance to minimize sources of radiant heat.

The total workday loss due to inclement weather conditions (heat stress, strong wind speed, and low temperature) is 31 days a year. The workday loss from heat stress alone is 24 days a year. The impact of inclement weather on each month is summarized in Table 3.

Table 3 – Workday Loss Distribution by Month

	Day Loss due to Heat Stress	Day Loss Due to Strong Wind	Day Loss Due to Low Temperature	Total Workdays Lost
January	0	0.425	0.9	1.325
February	0	0.425	0	0.425
March	0	0.425	0	0.425
April	0	0.425	0	0.425
May	0.22	0.425	0	0.645
June	2.47	0.425	0	2.895
July	9.5	0.425	0	9.925
August	9.4	0.425	0	9.825
September	1.73	0.425	0	2.155
October	0.14	0.425	0	0.565
November	0	0.425	0	0.425
December	0	0.425	0.9	1.325

SIMULATION RESULT

The weather impacts on LEU Loading Station Operations are different each month. The heat stress impact on LEU loading operations is concentrated in the months of July and August while the low temperature impact is on December and January. The impact from heat stress is much more than from low temperature, therefore, it would require more manpower in summer than in spring, fall, and winter to produce the same amount of canisters. The manpower required and crews' utilization rates for the LEU campaign are given in Tables 4.

Table 4 – Resource Required for Each Month

	Crew Utilization Rate	Shift and Number of Crews Required
January	86.6%	1 Crew, 7 Days a Week
February	93.5%	1 Crew, 7 Days a Week
March	84.5%	1 Crew, 7 Days a Week
April	87.3%	1 Crew, 7 Days a Week
May	84.9%	1 Crew, 7 Days a Week
June	92.8%	1 Crew, 7 Days a Week
July	86.0%	2 Crews, 6 Days a Week
August	86.0%	2 Crews, 6 Days a Week
September	90.9%	1 Crew, 7 Days a Week
October	84.5%	1 Crew, 7 Days a Week
November	87.3%	1 Crew, 7 Days a Week
December	86.6%	1 Crew, 7 Days a Week

PROCESS OPTIMIZATION

For one crew operation in LEU Loading Station, all functions are in series. No process optimization is required. However, for two crews operations, many functions are in parallel. Process optimization is essential.

Constraints and Resource Available

1. Maximum Number of Containers Can be opened at one time = 3
2. Only one container can be filled at a time
3. Three Fill Lines, Line 1 serves containers 1,2,3; Line 2 serves 4,5,6, Line 3 serves 7,8,9.
4. Three Bridges
5. Two impact wrenches
6. Measuring tank can't be filled if there is no fill line connected to container
7. One or two crews. One crew comprises of 2 Ops, 1 RCO.

The constraints 1, 2, 6 are imposed by NCSE [NCSE, 2001].

The working space in the LEU Loading Station platform is fairly limited. To arrange two crews working simultaneously is to avoid two crews working on containers next to each other to minimize potential interference. To accommodate the constraints and space limitation, it is recommended to fill containers in the following order:

1. 1st three containers - 1, 6, 9.
2. 2nd three containers - 2, 4, 8
3. 3rd three containers - 3, 5, 7

The constraints and resources are can be loaded into functions to model the LEU loading operations. The process optimization are accomplished by:

- Load resources and let functions to compete limited resources
- Assign AND Gates to connect the functions that can be performed in parallel:

1. Prepare Container for Filling
2. Attach Vent and Fill Line
3. Fill Measuring Tank and Containers
4. Disconnect Vent and Fill Line
5. Close Container

The optimized process steps determined by the model are given in Figure 1 and Figure 2 below.

CONCLUSION

A modified algorithm for calculating WBGT in a partially enclosed structure such as the LEU Loading Station in H-Area, using readily available standard meteorological data, has been developed. A brief field study suggests that this algorithm can provide users acceptable results for use in heat stress evaluations.

The total workday loss due to inclement weather conditions (heat stress, strong wind speed, and low temperature) is 31 days a year. The workday loss from heat stress alone is 24 days a year.

With one single crew, the following months will have problem to meet required throughput:

Campaign Phase	Months Can't Meet Required Throughput
Peak Monthly Rate	July, August

Removing air conditioning from LEU Loading Station has a significant impact on resource requirements in months of July and August.

For a single crew, the task time to complete loading a trailer with 9 canisters is 55 hours, and with 2 crews, the task time is 33.3 hours. Compared to a single crew, the double crews' efficiency is 75%.

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BIOGRAPHY

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Chuck Hunter, Fellow Scientist, Atmospheric Technologies Group, WSRC. More than 20 years experience in applied meteorology for WSRC, U.S. Army, and the Tennessee Valley Authority.

C stands for Container

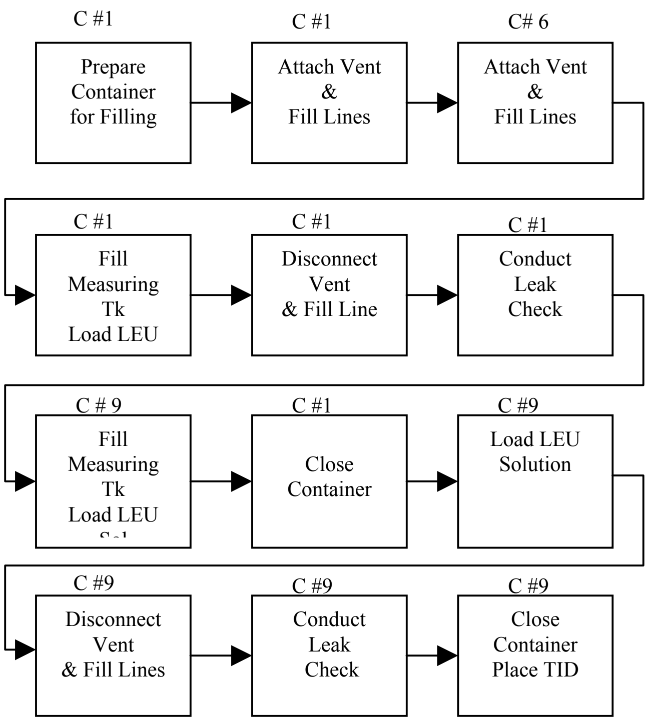

Figure 1. The Optimized Process Flow Diagram for the Crew #1

C stands for Container

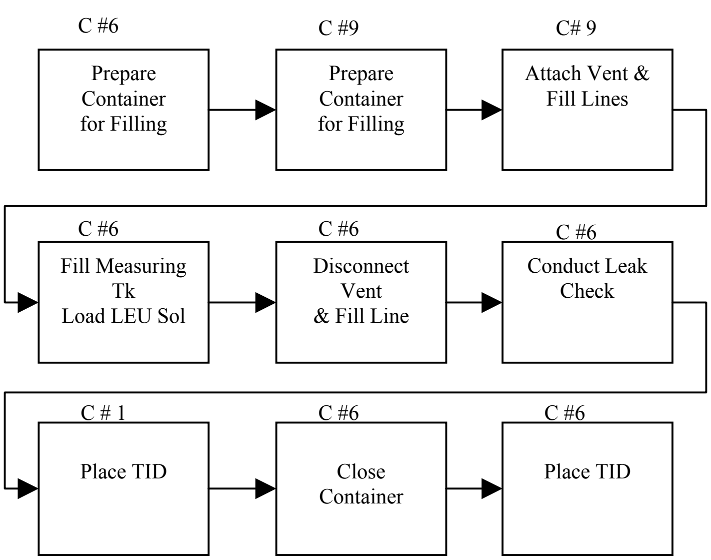

Figure 2. The Optimized Process Flow Diagram for the Crew #2