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A NUCLEAR CRITICALITY SAFETY ASSESSMENT OF THE CONSOLIDATED EDISON URANIUM-SOLIDIFICATION PROGRAM FACILITY

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ABSTRACT

A nuclear criticality assessment of the Consolidated Edison Uranium-Solidification Program facility confirms that all operations involved in the process may be conducted with an acceptable margin of subcriticality. Normal operation presents no concern since subcriticality is maintained by design. Several recommendations are presented to prevent, or mitigate the consequences of, any abnormal events that might occur in the various portions of the process. These measures would also serve to reduce to a minimum the administrative controls required to prevent criticality.

1. INTRODUCTION

A nuclear criticality safety assessment of the Consolidated Edison Uranium-Solidification Program (CEUSP) facility was performed to demonstrate subcriticality during normal operation of the process and to identify those administrative or other types of control measures required to prevent criticality when abnormal events occur. During normal operation, subcriticality is maintained by design. The vessels are of dimensions and capacities incapable of sustaining criticality independently, and they are arranged and spaced in a manner that ensures subcriticality as a system. In making the assessment, a total loss of material control was assumed rather than postulating various sequences of abnormal events that would result in accidental criticality. This assumption requires any fissile material that accumulates outside the process system to result in a configuration that will remain subcritical. Further, it leads to minimal dependence on administrative controls.

The neutron multiplication factor (k_{eff}) of the system and its components was estimated by calculations utilizing the CHERIE[1] Monte Carlo criticality code and the ENDF-IV cross sections prepared by the CSASIN module in the SCALE[2] system. The combination of code and cross sections preparation has been validated with critical experiments performed with ^{235}U and ^{233}U nitrate solutions in cylindrical and annular geometries as well as with arrays of the materials as subcritical components. The results of the comparisons establish biases between 2 and 3% in k_{eff}. However, the margin of subcriticality used as a criterion in these analyses is sufficient (~0.1 in k_{eff}) to preclude concern for the influence of the biases and their uncertainties on the subcritical state.

The Consolidated Edison uranium (CEU) solution is supplied to the process from the Thorium Reactor Uranium Storage Tank (TRUST) facility, where subcriticality is sustained either by the presence of borosilicate-glass Raschig rings or by the use of soluble neutron absorbers, cadmium and gadolinium. Each of these alone is sufficient to maintain subcriticality independent of the volume of solution or the geometry of its containment. While the soluble absorbers are expected to remain with the uranium through the oxide conversion procedure and to contribute an additional margin of subcriticality to the process, their presence is ignored in the analysis.

2. FISSILE MATERIALS

Calculations were performed with 100% ^{233}U, in the form of $UO_2(NO_3)_2$ solutions, at two uranium concentrations, 381 and 425 g/L, in addition to the CEUSP solution. The ^{233}U nitrate solution concentrations bracket the range in which the minimum critical volumes will occur for reflected and unreflected single vessels. These concentrations also provide neutron multiplication factors and concomitant neutron leakage fractions that are well suited to exhibit neutron interaction among the vessels in the process cell. Lesser concentrations than these are considered to result from the addition of water that may occur because of installed fire protection systems. The densities of the solution constituents used in the calculations appear in Table 1, where a concise description and concentration of the solution label the columns. This method of identifying the solutions is also used in the tables of results. It was assumed that no free acid was present in any of the solutions.

3. GEOMETRIC DESCRIPTIONS

A simplified flowsheet of the process is given in Fig. 1; the CEUSP control areas, Cells 3 and 4, are shown in Fig. 2. Figures 3 and 4 illustrate the arrangement of the process vessels in the west and east sides of Cell 3, respectively. The dimensions and locations of the vessels used as input to the CHERIE code were taken from the drawings listed in Table 2, which were provided by UCCND-Engineering. The concrete walls, floor, and roof of the cell and the vessels, major connecting pipes, enclosures, and biological shielding were described and

Table 1. Isotopic densities of constituents in uranyl nitrate solutions

Element	Code	Uranium concentration (g/L)								
		$^{233}UO_2(NO_3)_2$ solution			CEU solution					
		381	425	381 (35 kg U; 91.2 L)	381	381 (35 kg U; 91.2 L)	125 (plus 50 gal H_2O; 35 kg U; 280.5 L)	81.2 (35 kg U; 431.1 L)	56.4 (plus 50 gal H_2O; 35 kg U; 620.35 L)	125 (plus 50 gal H_2O and boron[a]; 77.5 kg U; 620.3 L)
^{235}U	92508				1.15952-4	1.15952-4	8.057078-5			8.057078-5
	92509				6.2733-4	6.2733-4	4.359086-4			4.359086-4
	92511							2.097466-5	1.457453-5	
	92512							1.37444-4	9.550501-5	
^{238}U	92852				6.52178-5	6.52178-5	4.531746-5			4.531746-5
	928[illegible]							1.39002-5	9.658738-6	
^{236}U	92600				5.41649-5	5.41649-5	3.763719-5	1.15444-5	8.02178-6	3.763719-5
^{234}U	92400				1.35576-5	1.35576-5	9.420679-6	2.889599-6	2.007877-6	9.420679-6
^{233}U	92300				9.49349-5	9.49349-5	6.596677-5	2.02339-5	1.405979-5	6.596677-5
	92308	4.924-4	1.14095-3	4.923998-4						
	92309	4.924-4	1.26772-4	4.923998-4						
Hydrogen		6.0644-2	5.8771-2	6.0644-2	5.86818-2	5.86818-2	6.114126-2	6.510067-2	6.560147-2	6.114126-2
Oxygen		3.8212-2	3.95274-2	3.8212-2	3.71102-2	3.71102-2	3.596923-2	3.42063-2	3.395[illegible]4-2	3.596923-2
Nitrogen		1.9697-3	2.5354-3	1.9697-3	1.94231-3	1.94231-3	1.34964-3	4.13975-4	2.876502-4	1.34964-3
Boron										4.648312-4

[a]Boron/uranium atomic ratio of 0.9.

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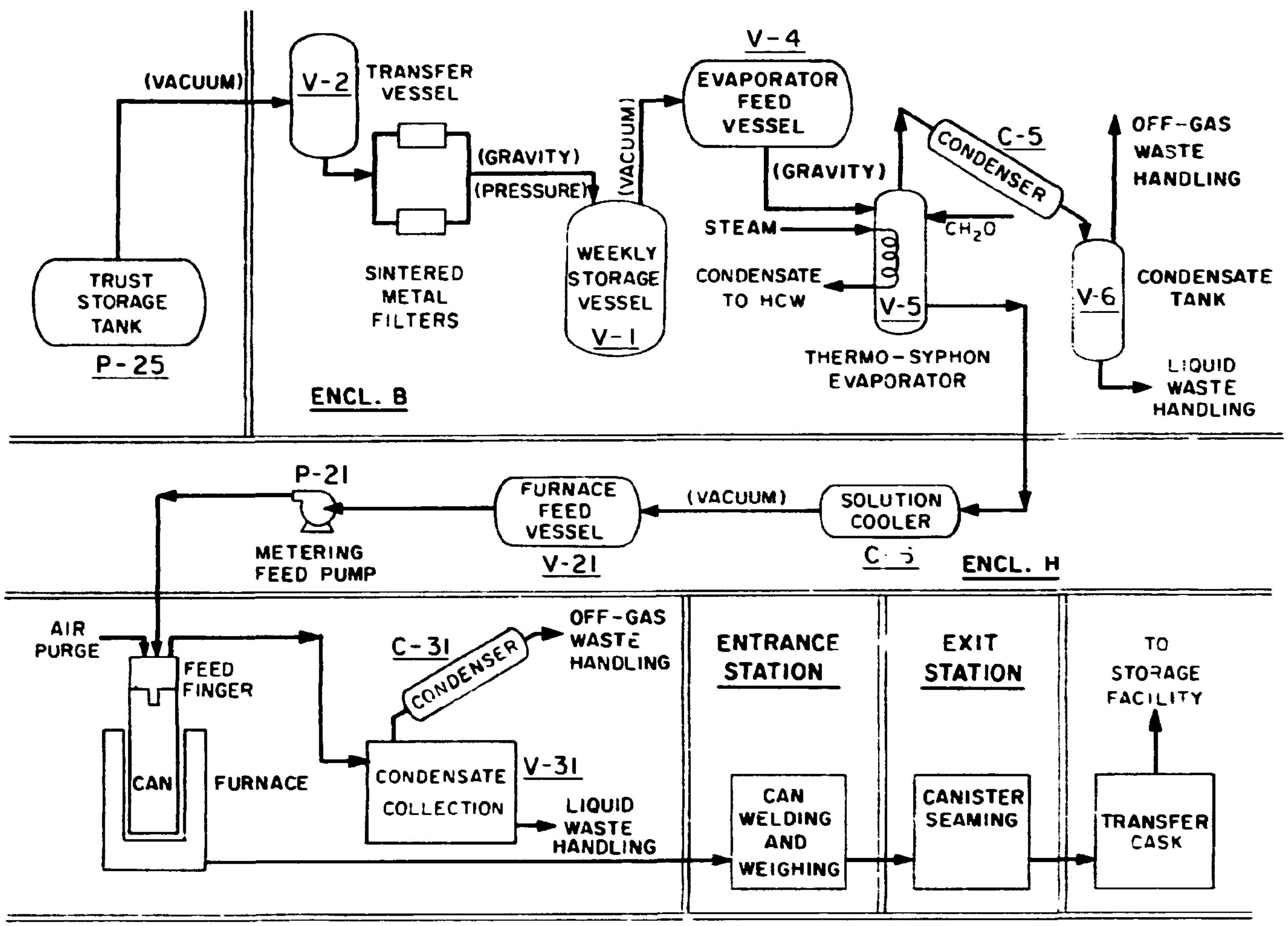

Fig. 1. Simplified flowsheet for process used in the CEUSP facility.

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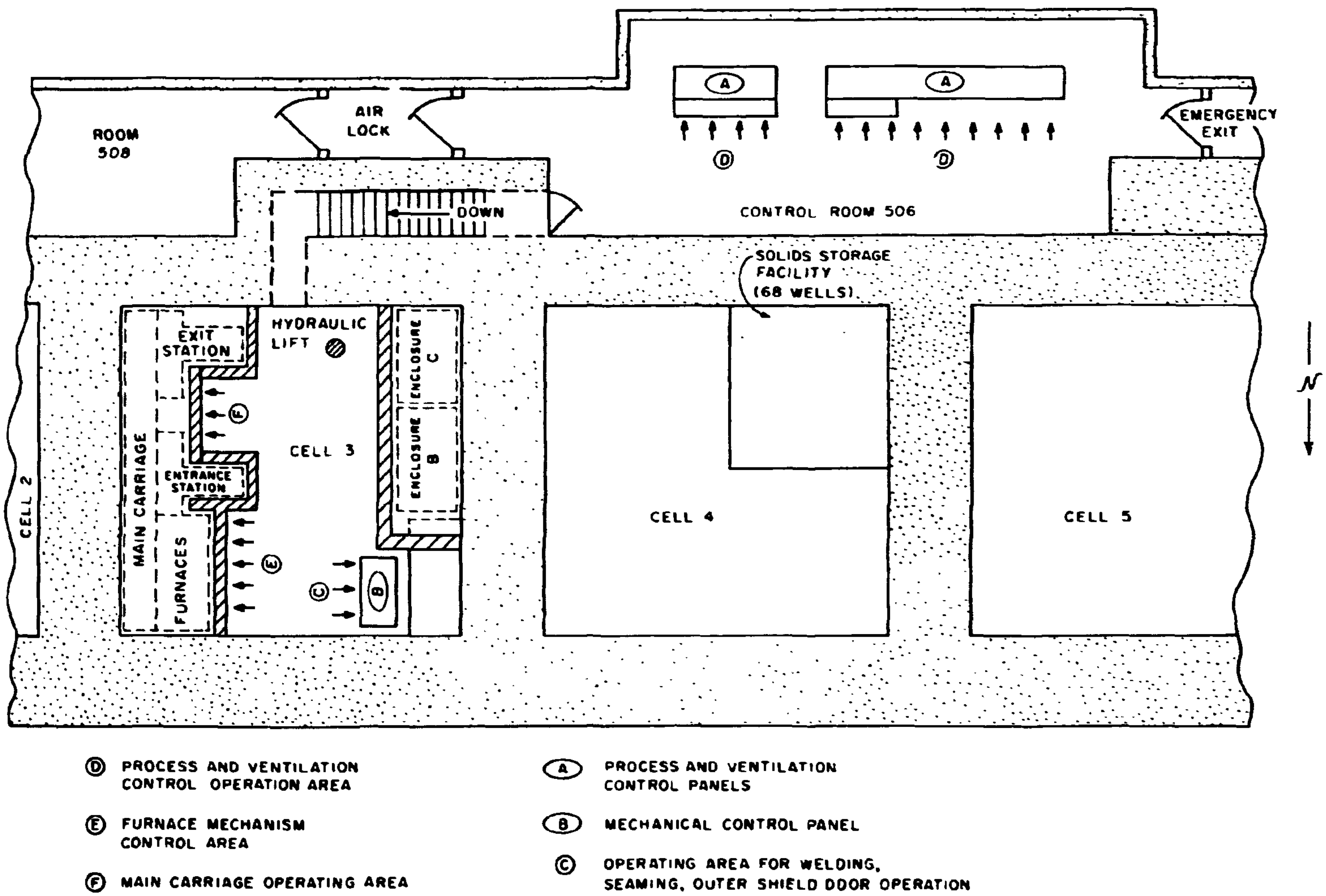

Fig. 2. Control areas in the CEUSP facility.

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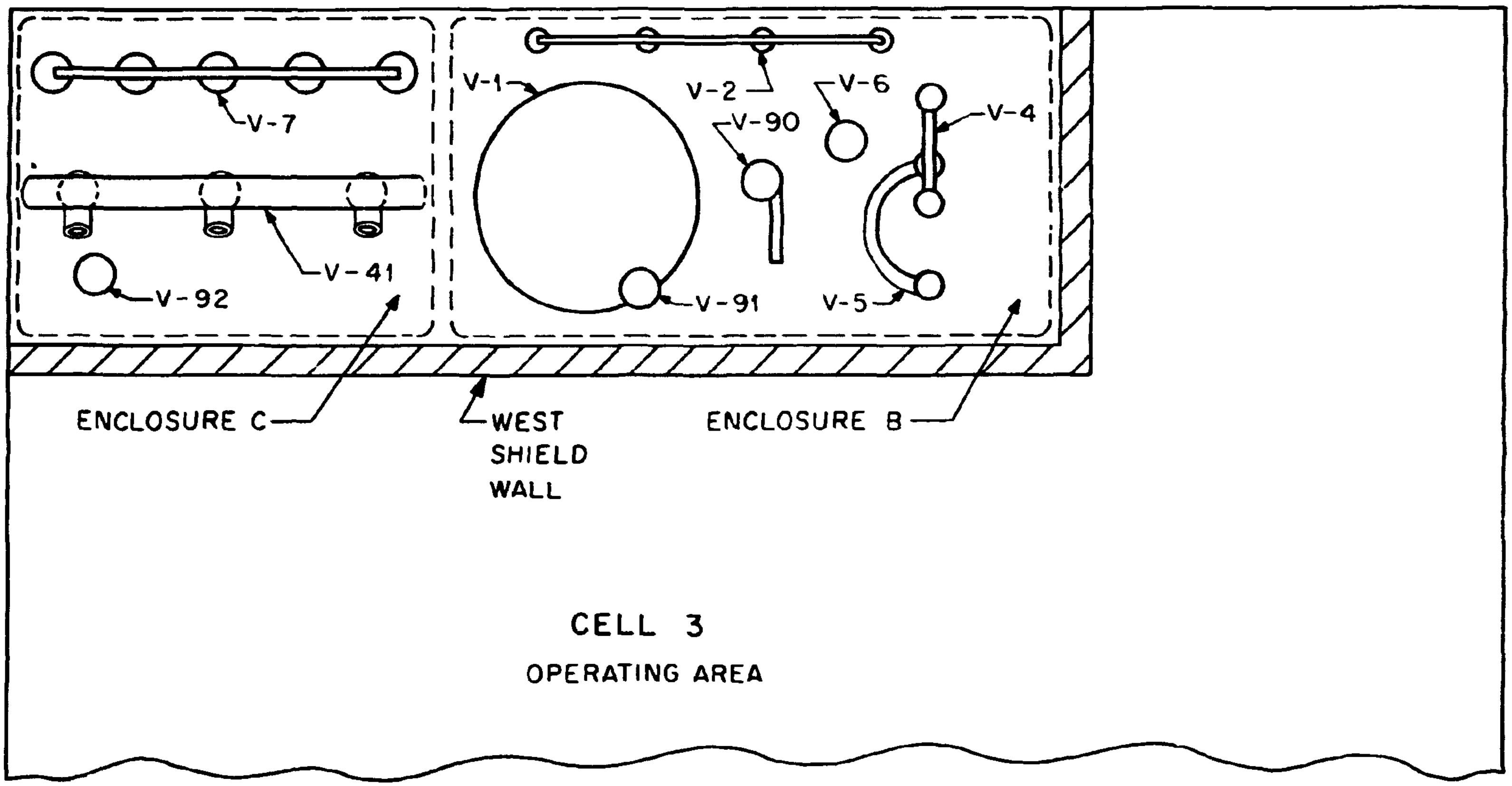

Fig. 3. Vessel arrangement on west side of Cell 3.

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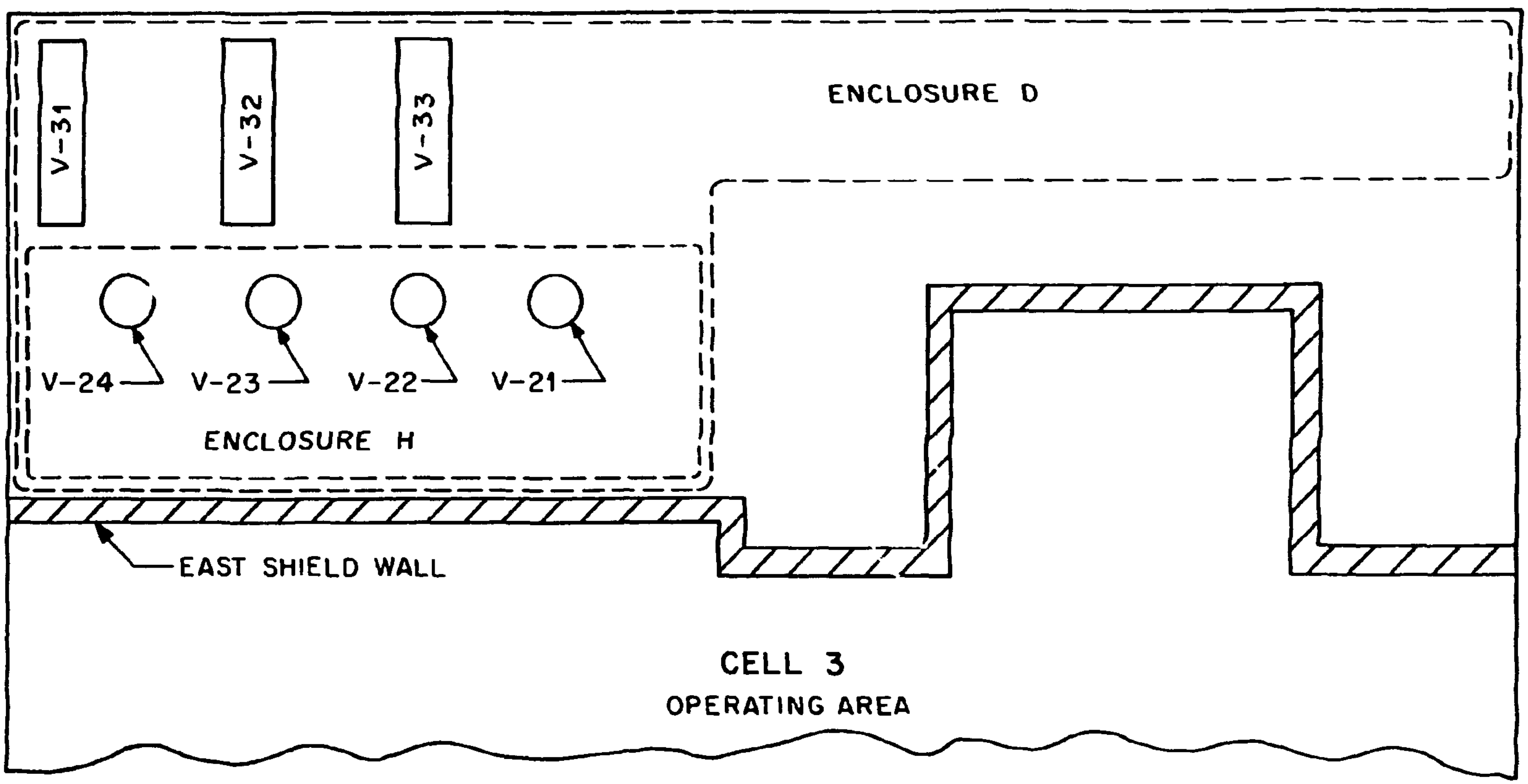

Fig. 4. Vessel arrangement on east side of Cell 3.

Table 2. List of drawings used to prepare computer code input

Drawing No.	Description
P3E 11834-C175	Cell 3 Process Equipment Assembly
P3D 11834-C060	V-26 Break Vessel
P3D 11834-C061	V-8 Syphon Break Vessel
P3D 11834-C062	V-2 Transfer Vessel
P3D 11834-C063	V-2 Transfer Vessel
P3D 11834-C064	V-6 Evaporator Condensate Vessel
P3D 11834-C065	V-6 Evaporator Condensate Vessel
P3D 11834-C066	V-90 Recycle Transfer Vessel
P3D 11834-C076	V-4 Dispensing Vessel
P3D 11834-C108	V-91 Solution Transfer Syphon Br[illegible] Vessel
P3D 11834-C133	V-4 Dispensing Vessel
P3D 11834-C137	V-7 Waste Vessel
P3D 11834-C138	V-41 Process Off-Gas Mixing Vessel and Assembly
X3E 11834-0900	Enclosure "B" Assembly
X3E 11834-0912	Enclosure "H" Assembly
X3E 11834-0913	Enclosure "H" Sections
X3E 11834-0936	North-East-South-West Elevations/Cell 3
X3E 11834-0940	Enclosures "H+D" Vessel Positions
X3E 11834-0941	Enclosure "B" Vessel Positions
X3E 11834-0942	Enclosure "C" Vessel Positions
J3E 11834-E142	V-5 — Assembly and Details
J3E 11834-E143	C5 — Assembly and Details
J3E 11834-E145	H5 — Assembly and Details
S3D 20327-B117	Floor Liners and Anchors Plans
S3D 20327-B118	Floor Liners and Anchors Section and Details
P-21040 CD E14 E	V-1 Vessel Assembly and Details
P3D 11834-C083	V-17 Concentrate Syphon Break Vessel Assembly
P3D 11834-C084	V-18 Concentrate Syphon Break Vessel Assembly
P3D 11834-C085	V-19 Concentrate Syphon Break Vessel Assembly
P3D 11834-C086	V-21 Concentrate Syphon Break Vessel Assembly
P3D 11834-C087	V-22 Concentrate Vessel Assembly
P3D 11834-C088	V-23 Concentrate Vessel Assembly
P3D 11834-C089	V-24 Concentrate De-entrainment Vessel

utilized in the calculations. The solution was considered to be present in any region of the cell in its normal configuration under the force of gravity.

4. CALCULATION OF NEUTRON MULTIPLICATION FACTORS

The mass of uranium assumed to be present in each portion of the process was determined by the capacities of the vessels and was recognized to be in excess of that considered a weekly inventory (~35 kg) in Cell 3. The quantities, however, provide evidence of the calculated k_{eff} response to changes in the parameters and permit conclusions to be drawn independent of a single result. The various portions of the process and conditions are described in Sects. 4.1–4.6. The calculations are numbered in Table 3 for easy reference.

4.1 ENCLOSURE C

Normal operations preclude the presence of significant quantities of uranium solution in Enclosure C; however, the conditions for subcriticality were determined in case an inadvertent transfer should occur. The results of calculations for the various described situations are presented in Table 3. In the first calculation, all the vessels of the enclosure are assumed to be filled with 100% ^{233}U nitrate solution at a uranium concentration of 425 g/L, which results in a supercritical configuration. The second and third calculations show that vessels V-7 and V-41 are subcritical individually when filled to capacity. The calculated k_{eff} decreases with a decreasing common height of solution in both vessels. Results at a ^{233}U concentration of

Table 3. Calculated results for Enclosure C

Calculation No.	Condition	Uranium conc. (g/L) ^{233}U	Uranium conc. (g/L) CEU solution	k_{eff}[a]	Mass (kg)	Volume (L)
1	Full	425		1.024 + 0.006	172.1	405.0
2	V-7 empty	425		0.807 + 0.006	58.3	137.3
3	V-41 empty	425		0.893 + 0.007	118.6	279.1
4	V-7 and V-41, 75% full; V-92 full	425		1.007 + 0.006	130.1	306.1
5	V-7 and V-41, 50% full; V-92 full	425		0.961 + 0.006	88.6	208.5
6	Full	381		1.018 + 0.006	154.3	405.0
7	V-7 empty	381		0.718 + 0.006	52.3	137.3
8	V-41 empty	381		0.894 + 0.006	106.3	279.1
9	Full		381	0.827 + 0.005	154.3	405.0
10	V-7 and V-41, 75% full; V-92 full		381	0.819 + 0.006	116.6	306.1
11	V-7 and V-41, 50% full; V-92 full		381	0.783 + 0.006	79.4	208.5

[a]Calculations made by using CHERIE code.

381 g/L (entries 6-8) depict similar behavior at expected lower values of k_{eff}.

CEU solution with a uranium concentration of 381 g/L results in subcriticality at an acceptable margin for uranium inventories in excess of twice that expected in the cell (entries 9-11).

4.2 ENCLOSURE B

The calculated results for Enclosure B are presented in Table 4. The first two entries indicate that the system is subcritical for ^{233}U nitrate solution by an adequate margin when the vessels are filled to capacity. They also show a reasonable response in k_{eff} resulting from the concentration change given. The actual CEU solution also produces subcriticality (entry 3) at a slightly larger margin than does the ^{233}U solution. A spillage of excessive mass to the free volume of Enclosure B is an unacceptable condition (entry 4) but would result in subcriticality when the uranium mass is only 35 kg (entry 6); however, the 50 gal of water in the enclosure fire protection system represents an undesirable second contingency which could result in a supercritical configuration (entries 5, 7, 8, and 9). Entry 10 demonstrates that the addition of boron to the water at a concentration corresponding to a boron/uranium atomic ratio of 0.9 would render an inventory of 77.5 kg of uranium subcritical in this configuration.

4.3 ENCLOSURES B AND C

Operations with CEU solution in Enclosure B at any concentration would not impact the margin of subcriticality in the event that a

Table 4. Calculated results for Enclosure B

Calculation No.	Condition	Uranium conc. (g/L) ^{233}U	CEU solution	k_{eff}[a]	Mass (kg)	Volume (L)
1	Full	425		0.881 + 0.006	183.2	431.1
2	Full	381		0.873 + 0.005	164.2	431.1
3	Full		381	0.711 + 0.006	164.24	431.1
4	Spill		381	1.395 + 0.006	164.22	431.0
5	Spill plus 50 gal H_2O		125	1.559 + 0.005	77.4	620.3
6	Spill		381	0.391 + 0.004	35.0	91.3
7	Spill plus 50 gal H_2O		125	1.129 + 0.006	35.0	280.5
8	Spill		81.2	1.295 + 0.005	35.0	431.0
9	Spill plus 50 gal H_2O		56.4	1.342 + 0.005	35.0	620.3
10	Spill plus 50 gal H_2O and boron (B/U = 0.9)		125	0.887 + 0.003	77.5	620.3

[a]Calculations made by using CHERIE code.

massive transfer of solution should occur to the vessels of Enclosure C. That is, no significant neutron interaction between Enclosures B and C would be observed:

Condition	Uranium conc. (g/L)	k_{eff} CHERIE	Mass (kg)	Volume (L)
Full	381	0.887 + 0.005	318.54	836.1

4.4 SOLUTION SPILLS TO FLOOR OF CELL 3

A massive spill of solution to the floor of Cell 3 is a very improbable event. Of course, there is a remote possibility that such a spill could occur from Enclosure B if both the equipment and the enclosure should fail. In that case, a volume of CEU solution (164 kg of uranium in 431 L) corresponding to the sum of the capacities of the vessels in Enclosure B would result in a critical condition if the solution were retained in the floor area bounded by the west shield wall. This calculated condition is the first entry of Table 5. The fire protection system of Enclosure B would exacerbate the condition if activated (entry 2). A similar volume of ^{233}U nitrate solution would also result in criticality; however, if the mass of ^{233}U were limited to 35 kg, the margin of subcriticality would be adequate even with the limited volume of water available from the fire protection system (entries 4 and 5). Further addition of water to the CEU solution containing a total of 35 kg of uranium would eventually result in criticality, as indicated by entries 6 and 7 of Table 5.

A spill of CEUSP solution over the entire floor area of Cell 3 (Table 6) would result in criticality because of the large floor sump.

Table 5. Calculated results for spill of solution to Enclosure B-C floor bounded by the west shield wall

Calculation No.	Condition	Uranium conc. (g/L) ^{233}U	Uranium conc. (g/L) CEU solution	k_{eff}[a]	Mass (kg)	Volume (L)
1	Spill to floor		381	1.002 + 0.005	164.25	431.1
2	Spill plus 50 gal H_2O		125	1.321 + 0.005	77.5	620.35
3	Spill to floor	381		1.178 + 0.006	164.25	431.1
4	Spill to floor	381		0.302 + 0.004	35.00	91.2
5	Spill plus 50 gal H_2O	125		0.748 + 0.006	35.00	280.5
6	Spill to floor		81.2	0.858 + 0.005	35.0	431.1
7	Spill plus 50 gal H_2O		56.4	1.092 + 0.005	35.0	620.35

[a]Calculations made by using the CHERIE code.

Table 6. Calculated results for spill of CEU solution to floor of Cell 3

Calculation No.	Condition	Conc. (g/L)	k_{eff}[a]	Mass (kg)	Volume (L)
1	Spill with sump	381	1.360 + 0.005	164.25	431.0
2	Spill with sump	381	1.243 + 0.005	35.0	91.2
3	Spill without sump	381	0.137 + 0.002	35.0	91.2

[a]Calculations made by using the CHERIE code.

Removal of the sump from the calculation (entry 3) shows very little neutron multiplication to occur for the limited uranium mass.

4.5 ENCLOSURE H

The calculated k_{eff} values for this enclosure (see Table 7) confirm the subcriticality of operations in the enclosure. The k_{eff} values, the distance between Enclosure H and B or C, and the intervening shielding walls obviate concern for neutron interaction.

Table 7. Calculated results for Enclosure H

Condition	Uranium conc. (g/L)		k_{eff}[a]	Mass (kg)	Volume (L)
	^{233}U	CEU solution			
Full	425		0.688 ± 0.005	23.7	55.7
Full		381	0.551 ± 0.005	21.2	55.7

[a]Calculations made by using the CHERIE code.

4.6 ENCLOSURE D

The can and canister assemblies containing the solidified uranium as an oxide have dimensions and capacities that are favorable to subcriticality. They are spaced within the enclosure and limited in numbers which preclude criticality. Storage of the canisters of $^{233}UO_2$ in Cell 4 is a routine operation which has received review and approval from the ORNL Criticality Committee.

5. DISCUSSION

The results of the calculated k_{eff} values clearly show that normal operations of the process can be conducted with an adequate margin of safety. It may be expected that the k_{eff} for the operation will not exceed a value of 0.9.

Loss of control of solution confinement, releasing a massive volume of solution which would overwhelm the sump transfer system capability of Enclosure B or of the floor, could result in a criticality incident. Limiting the mass of uranium to 35 kg mitigates the effect of such an abnormal event; however, the enclosure, its floor area as defined by the west wall shield, and the floor sump require additional actions. The sump will be rendered comparable to a water reflector in effectiveness by the addition of borosilicate Raschig rings. In this circumstance, the uranium mass limit of 35 kg spread over the floor of the cell as a slab of solution cannot be made critical at any concentration since the thickness required for criticality is always greater than that resulting from the addition of water to the solution. Enclosure B will require the addition of borosilicate-glass Raschig rings.

No action is required for Enclosure C since the double-contingency principle classifies a maximum uranium mass of 35 kg in a limited volume as an acceptable level of risk in the shielded area; that is, two or more unrelated events must occur before the potential for criticality exists.

Should an occasion arise for temporary accumulation and storage of UO_2 canister assemblies, the criticality indicator system[3] may be employed to define spacing for any number.

Finally, the preliminary calculations performed with 100% ^{233}U confirm the design of the process to be usable for the conversion of both ^{233}U and ^{239}Pu to oxide. However, a suitable mass limit for the cell should be determined in each case.

6. CONCLUSIONS AND RECOMMENDATIONS

Normal operations of the CEUSP facility can be conducted without concern for the risk of criticality. Addressing the single abnormal event, loss of control of massive volumes of CEUSP solution, obviates detailed consideration of various scenarios which may be conjectured as leading to a criticality incident. The regions of the cell identified as presenting a potential for criticality in the event that solution should accumulate in uncontrolled volumes are the cell floor sump and Enclosure B. Solution should not be confined to the cell floor area (under Enclosures B and C) bounded by the wall. It is recommended that borosilicate-glass Raschig rings, preferably the smaller 5/8-in.-OD size, be used in the floor sump. The void space in the bottom of Enclosure B should be filled with the larger borosilicate-glass Raschig rings.

7. ACKNOWLEDGMENTS

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