Credibility of a Criticality Accident in the C-712 Neutralization Pit

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ESO No. None

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1.0 Summary

The purpose of this evaluation is to show that a criticality due to the accumulation of uranium in the C-712 neutralization pit is not credible. This evaluation was developed to support a request for CAAS exclusion and does not establish a basis for nuclear criticality safety. The basis for nuclear criticality safety is established in NCSE 1493-25. Using event tree methodology, this evaluation confirmed that a critical configuration due to the accumulation of uranium in the C-712 Neutralization Pit is not a credible event.

2.0 Detailed Problem Statement

Justification for not having CAAS coverage of the C-712 neutralization pit is provided by an event tree analysis in Appendix E of NCSE 1493-25. The NRC has expressed a concern with what appears to be an assumption in the analysis of uniform settlement of uranium to the bottom of the pit. However, this concern is not warranted since the uniform distribution was only used to establish a conservative normal case concentration limit. This conservative condition of having the entire tank full of 0.34 g ^{235}U/l was then used in the process upset analyses to show the pit would remain subcritical following extremely conservative upset conditions (e.g. 5 cold traps dumped into the sink).

In establishing this concentration limit, the slab height and concentration was varied while keeping the uranium mass constant at 426.8 kg to demonstrate that 426.8 kg is subcritical at the optimal concentration/slab height. This subcritical mass times a safety factor of 0.225 was divided by the volume of the pit to derive the concentration limit of 0.34 grams ^{235}U per liter. Though at first glance it may appear that the use of the slab model to derive the concentration limit assumes that the uranium concentration is uniform in the horizontal plane, this is not the case. The analysis recognizes the potential for precipitation in the pit and states so in the conclusion of the NCSE. In addition, the fact that the NCSA requires samples from 11 different locations (e.g. 5 from the bottom) in the pit is evidence that it was recognized that the uranium in the pit may not be completely homogeneous.

The sample plan was established for the purpose of ensuring that potentially concentrated areas of the pit were sampled. Once a sample is found to exceed the limit, regardless of the location, the use of the drains in C710 shall be discontinued as stated in the NCSA 1493-25. Therefore, it does not matter if one location of the pit has a tendency to result in higher sample results because the pit will remain subcritical following all credible upset conditions with the entire tank at a concentration of 0.34 g^{235}U/l. In order to have a

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criticality in the pit the entire pit would have to be filled with a concentration greater than the always safe value of 11.6 g ^{235}U/l.[4.4] This is more than 30 times more material than is allowed by the sampling plan. If an area of the pit were to become concentrated it would be discovered long before the 11.6 g ^{235}U/l was ever reached.

Operations in C-710 are analytical in nature and not production oriented. Only small quantities of uranium are normally handled in the individual C-710 laboratories and the rate of uranium discharge to the drain system is very small. The monthly sampling has verified the small uranium quantities with concentrations in the PPM range. Thus, the required monthly sampling would alert NCS to higher than normal levels well before the uranium concentration reaches levels of concern. To illustrate, consider the hypothetical scenario where the 11 samples have concentration levels ranging from .10 to .34 grams ^{235}U per liter. Then, the uranium settles to the bottom in the most reactive slab configuration. The slab model in NCSE 1493-25 Appendix C bounds this scenario. The Appendix C model assumes a 0.34 g ^{235}U/l concentration at *all* locations in the pit before settling into the most reactive slab. In the scenario above, only one location in the pit has the maximum concentration of 0.34 g ^{235}U/l.

The current analysis adequately ensures the criticality safety of the C-712 pit and shows that a criticality is not credible. This Engineering Evaluation confirms the conclusion using an alternate approach. The approach is an event tree analysis assuming a conservative non-uniform settlement of uranium. In addition the overly conservative assumption of no uranium escaping from the pit during a month long period of process upsets has been removed. This evaluation was developed to support a request for CAAS exclusion and does not establish a basis for nuclear criticality safety. The basis for nuclear criticality safety is established in NCSE 1493-25.

The Appendix E event tree analysis in the C-712 NCSE is very conservative on the amounts of uranium discharged to the pit and the probabilities of the upsets. (For example, it is assumed that 3.81 kg uranium from a loaded cold trap is discharged to the pit every day for 30 days in a row from a room that doesn't have an opening to the pit and without the supervisor detecting it.) Nonetheless, the event tree analysis is performed in this evaluation using a nonuniform configuration to determine the maximum subcritical mass to demonstrate that a criticality in the C-712 pit is incredible. Note that the initiating event itself, the assumption of the entire pit having a uniform uranium concentration of 0.34 g/l (to conservatively maximize the amount of uranium in the pit) is inconsistent with the assumption of nonuniform uranium concentration.

3.0 Assumptions

The assumptions and bases for the assumptions are detailed in the section of the event tree analysis where they are used in section 6.

4.0 References

4.1 Spiceland, M.T., *Gaseous UF_6 Subsampling and Transfer*, CP4-TS-AS7104, Lockheed Martin Utility Services, Inc., Paducah, KY, May 11, 1995.

4.2 Burns, R. S. and Turner, J. H., Method Used to Estimate Screening-Level Failure Probability for Human Error Events, K/GDP/SAR-42, Martin Marietta Energy Systems, Inc., Oak Ridge, TN, July 1994.

4.3 Winiarski, R. J., NCS Evaluation for the Drain System in the C-710 Facility at the Paducah Gaseous Diffusion Plant, Lockheed Martin Utility Services, Inc., NCSE 1493-25 Rev. 2, Paducah, KY, March 1997.

4.4 *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, ANS/ANSI 8.1, 1983.

4.5 *SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation*, NUREG/CR-0200, Rev. 6 (ORNL/NUREG/CSD-2/R6), Vols. I, II, and III, September 1998.

4.6 M. W. Waddell, Jr., *Validation of the Paducah Gaseous Diffusion Plant Nuclear Criticality Safety Code System for the ENDF/B-IV 27 Group and ENDF/B-V 44 Group Cross Section Libraries*, KY/S-221 Rev. 4, United States Enrichment Corporation, January, 2000.

4.7 *Nuclear Safety Guide*, TID-7016, Rev. 2, Oak Ridge National Laboratory, 1978.

4.8 *CRC Handbook of Tables for Probability and Statistics*, 2nd edition, The Chemical Rubber Company, 1966, p. 283.

5.0 Impact on Nuclear Safety

This evaluation provides confirmation, using an alternate but conservative set of assumptions, that a critical configuration due to the accumulation of uranium in the C-712 Neutralization Pit is not a credible event. Therefore, nuclear safety is not adversely impacted.

6.0 Evaluation

6.1 C-712 Neutralization Pit Description

The C-712 Neutralization Pit, located underground near the southwest corner of Building C-710, receives liquid waste effluent from the process drains and sinks inside the building. The sinks and drains that flow to the neutralization pit are located in individual laboratories on the first floor of the building. The primary function of the neutralization pit is to neutralize acidic solutions originating in the various laboratories inside the building. Neutralization is accomplished through the dilution provided by the other waste streams in the building. Since the laboratories discard small quantities of uranium during normal operations, the potential for the accumulation of the discarded uranium into a critical configuration was semi-quantitatively evaluated.

As discussed in Appendix A of NCSE1493-25, the neutralization pit is 8.54 ft long by 6.41 ft wide by 10 ft deep. The pit is provided with a vertical barrier in the center of the pit slightly elevated above the bottom. The pit discharge pipe to the sanitary sewer is on the opposite side of the barrier from the C-710 inlet pipe which forces the effluent to the bottom of the pit before it flows up and out the discharge line. This design increases the turbulence and therefore reduces the tendency of the uranium to settle near the bottom of the pit. The sampling data documented in Appendix A of NCSE 1493-25 indicates that the uranium discharged to the drain system does not appreciably settle to the bottom of the neutralization pit.

In order to preclude a criticality in the neutralization pit, control measures documented in NCSE 1493-25 Sect. 5.2 will be applied. In addition to the control measures applied specifically to the pit, all of the fissile material operations performed in Building C-710 have separate NCSAs with criticality controls that provide defense-in-depth. This analysis postulates failure to follow the recommended conditions of approval. The frequency of forming a critical configuration in the neutralization pit assuming failure to follow the recommended conditions of approval is conservatively estimated using the event tree shown in Fig. 3. The initiating event and event tree events are discussed in more detail in later sections of this report.

Recommended conditions of approval from NCSA 1493-25 pertinent to this analysis are listed below.

- The enrichment of uranium handled in the laboratories which drains to the neutralization pit is limited to 5.5 wt % ^{235}U, when the potential exists for introduction of material into the drain system. (NCSA GEN-32 controls the handling of samples that exceed 5.5 wt % ^{235}U to minimize the potential for introduction of higher assay material into the drain. NCSE 1493-25 considered the inadvertent introduction of higher assay material into the drain.)

- The floor drains in rooms where carboys are used to store fissile and potentially fissile samples are sealed with epoxy and inspected annually to preclude the inadvertent introduction of uranium contaminated lab waste through the floor drains.

- The neutralization pit is sampled on a monthly basis and operations are suspended if the concentration exceeds 0.34 grams ^{235}U per liter.

- The tube wash system located in Room 21 of C-710 shall not wash more than 250 tubes per week.

- The cylinder wash system in Room 21 of C-710 shall not wash more than 120 cylinders per month.

Operations in C-710 are analytical rather than production oriented. As a result only small quantities of uranium are normally handled in the individual C-710 laboratories. NCSA controls require the collection of fissile and potentially fissile samples in a carboy that is geometrically favorable. Items to be washed are visually inspected prior to washing such that the rinsate from heavily contaminated items can be collected in a geometrically safe carboy. These normal operating procedures preclude the discharge of significant quantities of uranium to the neutralization pit.

Floor drains, in rooms where carboys are used, are sealed with epoxy and the seals inspected annually. Therefore, the frequency of a criticality in the neutralization pit due to erroneous discharges to these floor drains is not considered credible. The only room with an open floor drain that could be expected to receive fissile or potentially fissile waste solutions is Room 6. Room 6 is used for exposure testing of materials to be used in the cascade. It is not designated as a fissile material area and any UF_6 or UO_2F_2 used in the room is depleted in the ^{235}U isotope. Further analysis of accident scenarios involving the inadvertent release of uranium contaminated waste to the floor drains is not warranted.

Since the maximum product enrichment of the plant is limited to 5.5 wt% under HAUP, only standards and limited quantities of special material from offsite will exceed this enrichment in the C-710 laboratories. These operations are controlled by a separate operation-specific NCSA in which any discharges to the drain system would be severely restricted. As a result further analysis of events that result in the discharge of uranium that exceeds 5.5 wt % ^{235}U is not warranted.

6.2 Determination of Maximum Subcritical Mass in the C-712 Neutralization Pit

A parametric study was performed to determine the maximum subcritical mass in the C-712 pit for use in the event tree analysis. The fissile solution was modeled as two regions, a high uranium concentration region surrounded by a low uranium concentration region.

6.2.1 Calculational Method

All calculations were performed using the SCALE 4.4[4.5] code system. The control module CSAS25 was executed which in turn executed the SCALE functional modules BONAMI, NITAWL, and KENO V.a. BONAMI and NITAWL are cross section processing modules that produce a working cross section set applicable to a specific nuclear environment from a master cross section set (a general, problem independent cross section set). KENO V.a then calculates the effective multiplication factor (k-effective) of the system using the cross sections processed by BONAMI and NITAWL. The SCALE 27-group cross section library, based on ENDF/B-IV data, was used in all computations, which were performed on a Gateway 2000 PC, serial number 9441683, and a Compaq Deskpro, serial number 6923CDDZA407. The validation of SCALE 4.4 at PGDP is documented in KY/S-221 Rev.4.[4.6]

The calculations performed to determine the maximum subcritical mass in the C-712 pit are within the range of applicability of the SCALE 4.4 validation. Uranyl fluoride solutions are present in many of the caa and cas series benchmarks. In these calculations the enrichment was 5.5%, the hydrogen to ^{235U} ratio varied from 600 to 1500[+], and the average energy group causing fission (AEG) was 24.2. This compares to the SCALE 4.4 validation values of 0.71% to 9.84% enrichment, a hydrogen to ^{235}U ratio of 17 to 3134, and 12.7 to 24.8 AEG. A system was considered subcritical if the system k-effective plus twice the standard deviation was less than the upper safety limit of 0.9634 as specified in TSR 3.11.4.

6.2.2 Calculational Model

The KENO model of the C-712 pit consists of a cylindrical region of a uranyl fluoride solution on the floor of the pit surrounded by uranyl fluoride solution having a lower uranium concentration. The total amount of uranium is held constant at 150 kg with an enrichment of 5.5%. Above the solution is ten feet of water while the bottom and sides of the pit are modeled as concrete slightly greater than one foot thick.

The ratio of the uranium concentration in the high concentration region to that in the low concentration region is held constant. The higher this ratio, the higher the reactivity of the pit. At one extreme, a ratio of one is equivalent to a slab of uniform concentration. At the other extreme, a ratio of infinity produces a cylinder in the central portion of the pit containing all the uranium surrounded by water. For this case, the optimum shape would be a square cylinder (height to diameter ratio of 1) which is nearly as reactive as a sphere.[4.7]

[+] The series of calculations with a uranium concentration of 100 g/l have hydrogen to ^{235}U ratios and AEG values that are out of the range of applicability of the validation, but the k-effectives of these cases are as expected extremely low and therefore this is not a concern.

To determine the concentration ratio, the following was considered. The relatively large volumetric flow rate through the pit would tend to promote a homogeneous mixture of uranium. The water inventory of the pit changes completely every two to three days (average flow of 2300 gallons per day). The pit has a vertical barrier in the center of the pit slightly elevated above the bottom. This feature increases the turbulence and therefore tends to produce a more uniform uranium concentration.

Table 1 lists the monthly measured ^{235}U concentrations on the bottom of the C-712 neutralization pit for 38 months. Samples were taken in each corner of the pit (e.g. NW = northwest corner) and in the center of the pit. The ratio of the maximum uranium concentration to the average of the four lowest concentrations for each month is also listed. Note that the highest measured concentration is not always in the same location, which is another indication of the dynamic flow conditions in the pit. The average of the maximum to average concentration ratio in the pit for the 38 months is 2.33 with a standard deviation of 0.95. The upper one-sided 95% confidence limit for the distribution of maximum to average concentration ratios is

$$LIM = M2A + t_{95,37}\, s,$$

where

LIM = one-sided 95% confidence limit,
M2A = average maximum to average uranium concentration ratio,
$t_{95,37}$ = statistical multiplier that determines 95% confidence band for 38 (n-1 degrees of freedom) data points determined from the student t-distribution, and
s^2 = variance.

For 38 data points and 95% confidence, $t_{95,37} = 1.688$[4.8] which results in an upper one-sided 95% confidence limit of 3.93. In the KENO model, the ratio of the uranium concentration in the high concentration region to the low concentration region is conservatively assumed to be 5.

The calculations were performed for several uranium concentrations ranging from 100 to 700 grams per liter in the high concentration region to ensure that the optimum uranium concentration was considered. For each uranium concentration, a series of calculations were performed varying the size of the central high concentration region to determine the optimum configuration. As the diameter of the central high concentration region increases, the fissile solution height must decrease to conserve the uranium mass of 150 kg. Height to diameter ratios varied from 0.077 to 4.57.

Table 1 U^{235} Concentration (mg/l) Versus Location at Bottom of Pit

Date	NW	SW	NE	SE	Center	Avg.	Max/Avg⁺
9/11/95	1.90	2.90	1.60	1.40	3.70	2.30	1.90
2/22/96	3.00	5.10	2.00	4.00	5.00	3.82	1.46
7/29/96	3.60	4.30	.30	7.00	5.40	4.12	2.06
8/27/96	.50	5.50	3.30	.30	.20	1.96	5.12
9/18/96	7.00	6.50	5.80	6.50	5.50	6.26	1.15
10/25/96	2.00	4.70	4.40	.30	4.50	3.18	1.68
11/1/96	1.70	3.50	4.60	4.10	6.30	4.04	1.81
12/10/96	3.40	4.40	4.30	2.90	4.10	3.82	1.20
1/3/97	4.70	7.40	4.50	.00	.00	3.32	3.22
2/24/97	4.40	7.60	4.50	2.90	5.90	5.06	1.72
3/4/97	1.10	4.60	.20	2.10	6.10	2.82	3.05
4/1/97	1.40	2.30	1.60	1.90	6.60	2.76	3.67
5/6/97	13.30	5.00	4.00	6.00	5.50	6.76	2.60
6/2/97	.79	3.30	4.85	1.65	6.64	3.45	2.51
7/1/97	.92	3.98	6.53	.34	5.21	3.40	2.50
8/6/97	1.30	4.94	5.31	3.74	6.96	4.45	1.82
9/18/97	5.40	5.30	2.60	5.20	5.80	4.86	1.25
10/6/97	.30	5.89	3.71	1.93	2.18	2.80	2.90
11/19/97	.43	.75	2.20	1.80	6.20	2.28	4.79
6/11/98	1.60	2.80	2.13	3.75	2.13	2.48	1.73
7/11/98	2.87	2.10	3.40	1.00	4.90	2.85	2.09
8/6/98	.33	2.10	1.80	.61	4.80	1.93	3.97
9/3/98	.49	1.80	2.89	.61	4.00	1.96	2.76
10/1/98	1.79	1.21	2.83	3.20	3.70	2.55	1.64
11/20/98	.98	1.28	2.32	1.55	3.22	1.87	2.10
12/11/98	1.64	1.52	1.72	3.35	4.48	2.54	2.18
1/15/99	1.01	4.13	.78	1.34	3.95	2.24	2.33
2/5/99	2.42	1.48	2.22	2.53	3.62	2.45	1.67
3/1/99	.64	2.30	2.10	1.97	3.97	2.20	2.27
4/8/99	.28	3.49	.74	1.78	3.35	1.93	2.27
5/19/99	6.97	6.93	1.74	4.14	5.96	5.15	1.49
6/17/99	3.32	3.73	.29	2.54	5.27	3.03	2.13
7/15/99	5.17	.42	.13	1.45	7.43	2.92	4.15
8/6/99	6.12	5.69	3.63	3.98	7.36	5.36	1.52
9/3/99	3.26	5.65	1.25	1.97	4.92	3.41	1.98
10/1/99	5.54	6.41	1.89	.99	5.12	3.99	1.89
11/8/99	3.80	2.48	1.19	3.68	5.50	3.33	1.97
12/7/99	4.99	2.17	1.11	3.27	3.56	3.02	1.97

⁺ratio of maximum concentration to average of the 4 lowest samples

average maximum to average concentration = 2.33
standard deviation = 0.95

6.2.3 Typical SCALE 4.4 input

```
=csas25
     c-712 pit
27groupndf4    infhommedium
solnuo2f2    1  500.0  0.0 1.0   293  92235  5.5   92238 94.5    end
h2o          2             1.0   293                             end
reg-concrete 3             1.0   293                             end
solnuo2f2    4  100.0  0.0 1.0   293  92235  5.5   92238 94.5    end
end comp
 c-712 pit
read parm  tme=324 tba=10 gen=530 npg=1000 nsk=30 nub=yes plt=no
end parm
```

```
read geom
global unit 1
com=' length x width = 8ft 6.5in x 6ft 5in '
cylinder   1  1  35.56            22.452  0.0
cuboid     4  1  2p130.2 2p97.8   22.452  0.0
replicate  2  2  4r0.0             3.0    0.0  10
replicate  2 11  4r0.0           275.0    0.0   1
replicate  3 12  4r5.0             0.0    5.0   7
end geom
read bias id=500 2 11  id=301 12 18  end bias
read start nst=1
  xsm=-45.0 xsp=45.0
  ysm=-45.0 ysp=45.0
  zsm=0.001 zsp=22.0  end start
end data
end
```

6.2.4 Results

Table 2 lists the results of the parametric analysis. Figure 1 illustrates k-effective as a function of the size of the central large concentration region at four different uranium concentrations. Reactivity peaks in the range of thirty to forty centimeters for the radius of the central region. Initially, reactivity increases with increasing radius because the geometry approaches a more optimal shape (H/D = 1) and the region volume increases. At some point, reactivity decreases because the geometry is becoming less optimal (H/D below 1 and decreasing) and because of the increasing leakage due to decreasing fissile solution height. Figure 2 illustrates k-effective as a function of the uranium concentration in the large concentration region for a central region having a radius of 35.6 cm. Reactivity peaks around 500 g/l although the curve is fairly flat in the range of 450 t to 700 g/l.

The largest k-effective plus twice the standard deviation determined in the parametric analysis is 0.9557 which is less than the upper safety limit of 0.9634. A uranium mass of 150 kg at an enrichment of 5.5% is subcritical in the C-712 pit provided the high to low concentration ratio does not exceed 5.

Table 2 Results

Concentration (g/l)	Radius* (cm)	Height (cm)	K_{eff}	σ	AEG+
100	15.24	139.31	0.4153	0.0005	25.1
100	25.40	127.06	0.4937	0.0005	25.1
100	30.48	119.82	0.5133	0.0004	25.1
100	35.56	112.26	0.5266	0.0004	25.1
100	40.64	104.64	0.5348	0.0005	25.1
100	45.72	97.17	0.5411	0.0005	25.1
100	50.80	89.98	0.5444	0.0005	25.1
100	55.88	83.19	0.5476	0.0004	25.1
100	60.96	76.83	0.5478	0.0005	25.1
100	66.04	70.94	0.5477	0.0004	25.1
300	15.24	46.44	0.7335	0.0010	24.2
300	25.40	42.35	0.8449	0.0009	24.2
300	30.48	39.94	0.8665	0.0009	24.2
300	35.56	37.42	0.8806	0.0011	24.2
300	40.64	34.88	0.8862	0.0008	24.2
300	45.72	32.39	0.8852	0.0010	24.2
300	50.80	30.00	0.8821	0.0009	24.2
300	55.88	27.73	0.8726	0.0008	24.2
300	60.96	25.61	0.8624	0.0008	24.2
300	66.04	23.65	0.8501	0.0008	24.2
400	15.24	34.83	0.7933	0.0010	24.2
400	25.40	31.77	0.8996	0.0010	24.2
400	30.48	29.96	0.9212	0.0011	24.2
400	35.56	28.07	0.9316	0.0010	24.2
400	40.64	26.16	0.9340	0.0009	24.2
400	45.72	24.29	0.9284	0.0010	24.2
400	50.80	22.50	0.9210	0.0009	24.2
400	55.88	20.80	0.9080	0.0010	24.2
400	60.96	19.21	0.8940	0.0009	24.2
400	66.04	17.74	0.8782	0.0009	24.2
450	15.24	30.96	0.8105	0.0010	24.2
450	25.40	28.24	0.9146	0.0010	24.2
450	30.48	26.63	0.9362	0.0011	24.2
450	35.56	24.95	0.9449	0.0010	24.2
450	40.64	23.25	0.9436	0.0010	24.2
450	45.72	21.59	0.9381	0.0010	24.2
450	50.80	20.00	0.9280	0.0010	24.2
450	55.88	18.49	0.9164	0.0008	24.2
450	60.96	17.07	0.8993	0.0010	24.2
450	66.04	15.76	0.8821	0.0011	24.2
500	15.24	27.86	0.8213	0.0010	24.2
500	25.40	25.41	0.9271	0.0010	24.2
500	30.48	23.96	0.9454	0.0010	24.2
500	35.56	22.45	0.9535	0.0011	24.2
500	40.64	20.93	0.9504	0.0010	24.2
500	45.72	19.43	0.9440	0.0012	24.2
500	50.80	18.00	0.9308	0.0011	24.2

500	55.88	16.64	0.9163	0.0010	24.2
500	60.96	15.37	0.8976	0.0010	24.2
500	66.04	14.19	0.8796	0.0010	24.2
550	15.24	25.33	0.8313	0.0011	24.2
550	25.40	23.10	0.9297	0.0011	24.2
550	30.48	21.79	0.9464	0.0011	24.2
550	35.56	20.41	0.9534	0.0010	24.2
550	40.64	19.03	0.9518	0.0012	24.2
550	45.72	17.67	0.9436	0.0011	24.2
550	50.80	16.36	0.9305	0.0011	24.2
550	55.88	15.12	0.9155	0.0011	24.2
550	60.96	13.97	0.8924	0.0010	24.2
550	66.04	12.90	0.8725	0.0012	24.2
600	15.24	23.22	0.8342	0.0011	24.2
600	25.40	21.18	0.9324	0.0010	24.2
600	30.48	19.97	0.9491	0.0012	24.2
600	35.56	18.71	0.9501	0.0011	24.2
600	40.64	17.44	0.9488	0.0012	24.2
600	45.72	16.19	0.9384	0.0011	24.2
600	50.80	15.00	0.9228	0.0011	24.2
600	55.88	13.86	0.9046	0.0012	24.2
600	60.96	12.81	0.8867	0.0010	24.2
600	66.04	11.82	0.8634	0.0010	24.2
650	15.24	21.43	0.8370	0.0012	24.2
650	25.40	19.55	0.9300	0.0013	24.2
650	30.48	18.43	0.9444	0.0012	24.2
650	35.56	17.27	0.9480	0.0011	24.2
650	40.64	16.10	0.9459	0.0011	24.2
650	45.72	14.95	0.9311	0.0012	24.2
650	50.80	13.84	0.9180	0.0010	24.2
650	55.88	12.80	0.8983	0.0011	24.2
650	60.96	11.82	0.8794	0.0011	24.2
650	66.04	10.91	0.8552	0.0012	24.2
700	15.24	19.90	0.8332	0.0012	24.2
700	25.40	18.15	0.9261	0.0012	24.2
700	30.48	17.12	0.9400	0.0010	24.2
700	35.56	16.04	0.9427	0.0012	24.2
700	40.64	14.95	0.9349	0.0013	24.2
700	45.72	13.88	0.9255	0.0012	24.2
700	50.80	12.86	0.9090	0.0011	24.2
700	55.88	11.88	0.8913	0.0012	24.2
700	60.96	10.98	0.8695	0.0013	24.2
700	66.04	10.13	0.8455	0.0010	24.2

* Refers to high concentration region.

+ AEG is the average energy group causing fission.

FIGURE 1 K-EFFECTIVE VERSUS URANIUM CONCENTRATION AND HIGH CONCENTRATION RADIUS

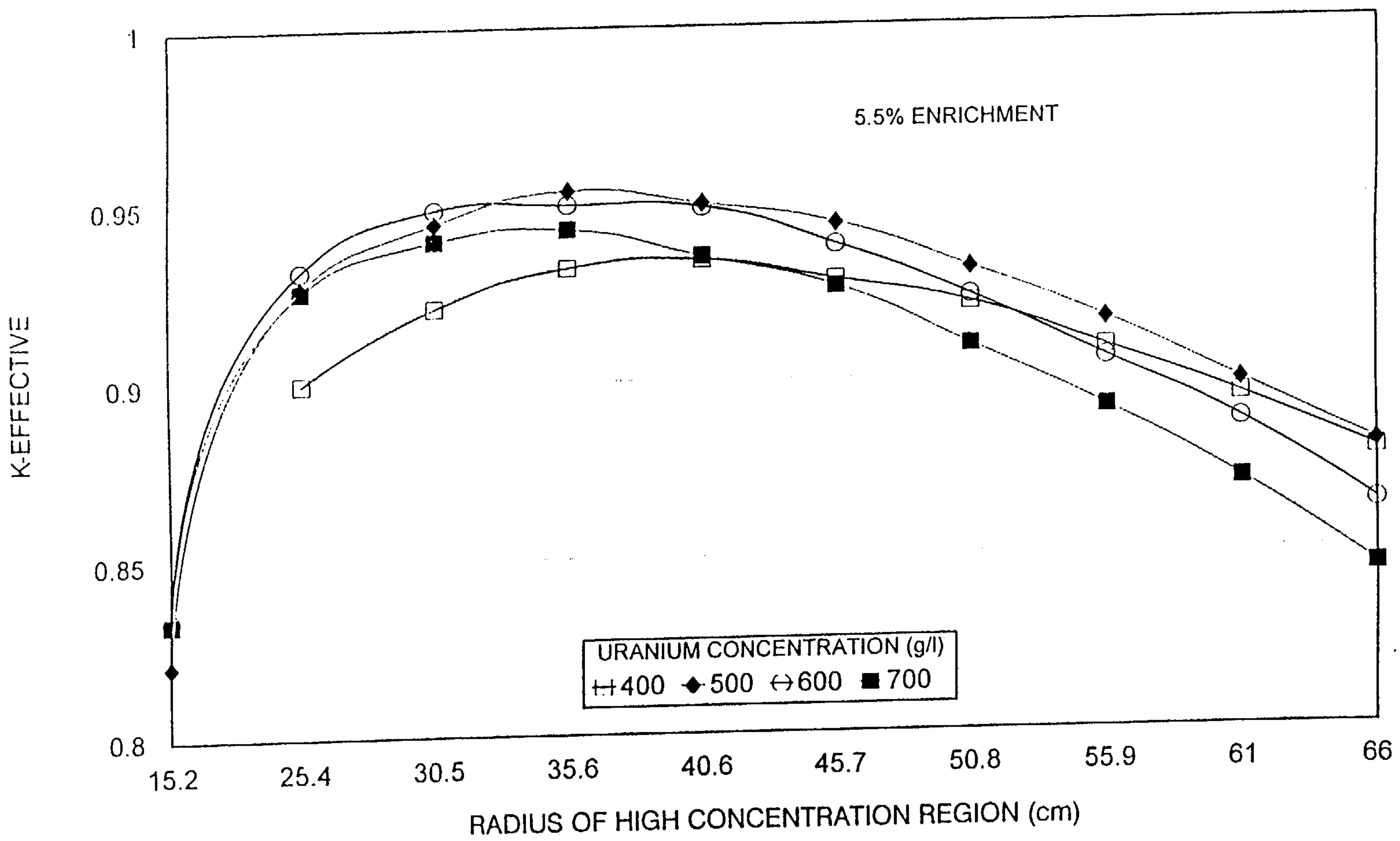
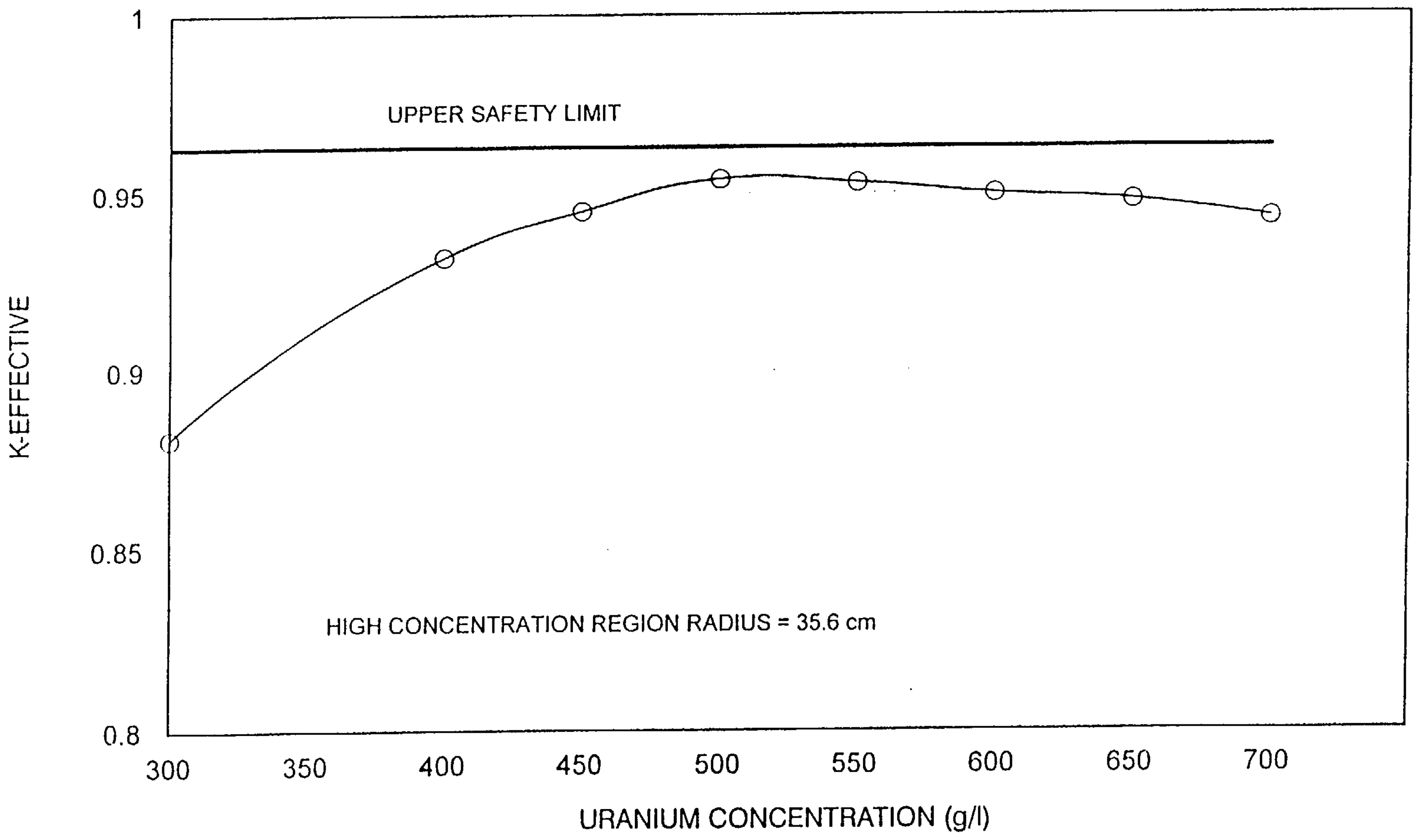


FIGURE 2 K-EFFECTIVE VERSUS URANIUM CONCENTRATION



6.3 PITCRIT EVENT TREE

The PITCRIT Event Tree, shown in Fig. 3, models accident scenarios that could cause an uranium mass approaching the maximum subcritical mass (150 kg U) to accumulate in the C-712 Neutralization Pit. The initiating event and event tree events are described in subsequent sections of this analysis. It should be noted that since some of the errors discussed below involve the same individuals, the event tree modeled dependencies between the event tree events.

6.3.1 PITCONC Initiating Event

The PITCONC initiating event postulates failures in the nuclear criticality safety control system that would permit the uranium concentration in the pit to exceed the control value of 0.34 grams ^{235}U/liter. As discussed in Sect. 4.2 of NCSE 1493-25, single or even multiple failures of the controls in place would not result in the pit concentration exceeding this value. This maximum permissible concentration was based on the following conservative assumptions:

- the assay of the pit is 5.5 wt % ^{235}U,
- the pit contains its maximum volume of 15,520 liters, and
- the permissible uranium loading of the pit is 96.03 kg of uranium.

The conservative nature of these assumptions is addressed below.

The assays of uranium handled in the C-710 laboratories are representative of operations conducted across the PGDP site. While some of the samples handled at the lab in the future will be at the Higher Assay Upgrading Project (HAUP) maximum enrichment of 5.5 wt% ^{235}U, approximately one-third of the samples will be from the tails, feed, and lower enrichment portions of the cascade where the enrichment is between 0.25 and 1.0 wt % ^{235}U. These enrichments can not cause a critical configuration without significant outside manipulation of the system that is intended to cause a criticality. While these lower enrichments provide a marginal contribution to the ^{235}U inventory, their higher ^{238}U content tends to reduce the reactivity of the neutralization pit. At a PGDP maximum plant product enrichment of 2.0 wt % ^{235}U, the assay of initial samples taken from the neutralization pit averaged 0.6326 weight percent ^{235}U or approximately 30% of the maximum enrichment. Extrapolating these results to HAUP operations at a maximum product assay of 5.0 wt % ^{235}U results in an average pit assay of 1.58 wt % ^{235}U, significantly less than the 5.5 wt % assumed for the maximum pit concentration calculation in Appendix A of reference 4.3.

The pit is assumed to contain 15,520 liters, based on the given dimensions, so as to make the maximum permissible concentration as low as possible. However, the neutralization outlet pipe to the sanitary sewer is 7 ft above the bottom of the pit restricting the usable

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The pit is assumed to contain 15,520 liters, based on the given dimensions, so as to make the maximum permissible concentration as low as possible. However, the neutralization outlet pipe to the sanitary sewer is 7 ft above the bottom of the pit restricting the usable pit volume to approximately 10,864 liters. Therefore, the greatest uranium loading of the pit assuming an assay of 5.5 wt % and a maximum permissible concentration of 0.34 g ^{235}U/liter is 67.16 kg U, which is well below the permissible uranium loading of 96.03 kg U that was calculated assuming the maximum pit volume of 15,520 liters. It should be noted that this maximum permissible concentration is 200 times the average fissile concentration, 1.7E-03 g ^{235}U/liter, based on seven months of sampling data at the maximum 2 wt % ^{235}U operations (see Appendix E of reference 4.3). Following the transition to 5 wt % ^{235}U operations, the number and uranium mass of the samples is expected to remain approximately constant; only the ^{235}U mass of the samples is expected to increase. This increase is expected to be a factor of 2.5 (i.e., ratio of 5 wt % ^{235}U to 2 wt % ^{235}U). Based on 5.0 wt % ^{235}U operations, the average fissile concentration of the pit might be expected to be 4.25E-03 g ^{235}U/ liter (i.e., 2.5 times 1.7E-03g ^{235}U/l). Under these operating conditions, the maximum permissible concentration is 80 times the expected average concentration at 5.0 wt % operations.

The permissible uranium loading of 96.03 kg U is based on the maximum allowable mass of 426.8 kg U determined in Appendix C of reference 4.3. This maximum allowable mass was determined by a parametric study of the reactivity of the neutralization pit. The maximum allowable mass was multiplied by a safety factor of 0.225 to obtain the permissible loading of 96.03 kg U. This safety factor is one-half the 0.45 safety factor normally used to calculate the maximum safe mass for nuclear criticality safety purposes. This more conservative safety factor enhances the criticality safety controls implemented for the neutralization pit operation.

The neutralization pit is approximately 70% full during normal operations. The average flow rate through the pit is approximately 2300 gallons per day. Based on available information, the water inventory of the pit changes completely every two to three days. Therefore, it is not considered credible for large deposits of uranium to accumulate and settle to the bottom under such dynamic conditions of flow.

Seven months of sampling data for the neutralization pit at 2.0 wt % operations (see Appendix E of reference 4.3), indicates a maximum fissile concentration in the pit of 7.6E-03 g ^{235}U/l. Assuming an assay of 5.5 wt % following the implementation of HAUP, this fissile concentration is expected to reach 1.9 E-02 g ^{235}U/l (i.e., 2.5 times 7.6E-03 g ^{235}U/l) corresponding to a pit inventory of 3.75 kg U for the 10,864 liter usable volume. In order to reach the maximum allowable fissile concentration of 0.34 g ^{235}U/l, approximately 63.41 kg U at a maximum 5.5 wt % ^{235}U must be added to the 3.75 kg U already in the pit. The frequency of such a large quantity of uranium of any enrichment being added to the pit over a short period is estimated to be 0.10/year based on the routine inventory of sample material present in C-710.

The probability that the uranium added to the pit is all 5.5 wt % ^{235}U is conservatively estimated to be 1.0. This is extremely conservative since approximately 33% of the samples processed in C-710 are less than 1.0 wt % ^{235}U. Although the probability of disposing of lower enrichments is greater than that cited for 5.5 wt % ^{235}U, the mass of uranium disposed of would have to be increased in order to exceed the maximum allowable fissile concentration of 0.34 g ^{235}U/l. Therefore, the frequency of the pit fissile concentration equaling or exceeding 0.34 g ^{235}U/l (more than 17 times the expected maximum concentration at 5.0 wt % operations) is conservatively estimated to be 0.1/year. Mishandling of laboratory samples that would cause the fissile concentration to exceed 0.34 g ^{235}U/l is the PITCONC initiating event and is estimated to occur with a frequency of 0.1/year.

In order to determine if a single act of accidental discharge is a criticality concern, the number and size of the largest containers routinely handled was evaluated. Since the C-710 laboratories are analytical in nature, only small sample-size (55 g U) quantities are commonly handled. Although the largest uranium-bearing containers routinely handled is a metal cold trap with a maximum volumetric inventory of 3.81 kg uranium, Room 37 where metal cold traps are processed does not contain an opening to the neutralization pit. In fact the material accumulated in metal cold traps is refed to the enrichment cascade in Building C-360. It should also be noted that the metal cold traps are routinely emptied after three months of service such that they contain no more than 1 kg U. Glass cold traps are the second largest sample containers by volume with a maximum inventory of 2.69 kg uranium. These traps are removed from the mass spectrometer and hydrolyzed at the end of each day. As a result of the daily hydrolyzation, the nominal inventory of the glass cold traps is closer to 10 grams uranium. Room 53, where the glass cold traps are handled, contains a sink that empties to the neutralization pit. During normal operations, the glass cold traps are hydrolyzed by adding water to the cold trap while it is in a bucket. The solution of uranium that results from the hydrolyzation process is discarded to a carboy located in the room. The number of glass cold traps present in the hood is limited by an NCSA to 5 or less resulting in a maximum hood inventory of 13.45 kg uranium conservatively assuming the volumetric capacity of the cold trap is filled with uranium. In order to exceed the minimum critical mass of 22.3 kg uranium, nine glass cold traps (four more than authorized) would have to be present in Room 53. The frequency that the room limit of 5 would be exceeded by 4 traps is extremely low. The probability that the glass cold traps would contain 2.69 kg U is unlikely considering that during normal service these traps are hydrolyzed once a day so that they contain less than 10 grams. The probability that the inventory of the glass cold traps would be erroneously discarded directly to the drain is unlikely based on operator training. The subsequent accumulation of the contents of these cold traps into a critical configuration is not considered credible. Therefore, a single accidental event that would result in the discharge of more than a minimum critical mass of uranium is not considered credible.

Based on the preceding discussion and the fact that the pit is sampled on a monthly basis, it is extremely unlikely that the fissile concentration of the pit would ever exceed the maximum permissible concentration of 0.34 g ^{235}U/liter. However, for the purposes of this analysis it is conservatively assumed that the concentration would equal or slightly exceed the maximum concentration 1 time in 10 years. The frequency of exceeding the maximum permissible concentration, the PITCONC initiating event, is conservatively assumed to be 0.1/ year.

6.3.2 SAMPLE Event Tree Event

The SAMPLE event models violation of the established procedures and criticality safety controls that specify fissile and potentially fissile samples shall not be disposed of down the drain. In this model the samples are erroneously drained to the neutralization pit via a cup sink. In Sect. 4.2.7 of NCSE 1493-25, it is assumed that for an entire month a sample per day is erroneously discharged to the pit from Room 53. Each sample is conservatively assumed to contain 3.81 kg U, the inventory of a metal cold trap. To demonstrate the conservative nature of this assumption, routine samples have an inventory of 55 g U. As previously discussed, the metal cold traps are refed to the cascade at C-360. The error considered in this event tree event involves failure to follow operating procedures by hydrolyzing the uranium in a metal cold trap and releasing the uranium solution directly to the drain system. In order to erroneously hydrolyze a metal cold trap, the operator must remove the metal cold trap valving which is not an activity encountered during the routine hydrolyzation of glass cold traps. This error repeated every day for 30 days would result in a total discharge of 114.3 kgs of U to the neutralization pit.

The metal cold traps are used to accumulate uranium from operation of the mass spectrometers. The metal cold traps are changed when the inventory of the trap contains 1,000 grams of uranium. Only 1 of the mass spectrometers is currently designed to accept metal cold traps. If this instrument were used on a daily basis, it would be changed approximately once every 3 months. Future plans call for the use of 11 total metal cold traps that would also require changing on a 3 month cycle. The probability that one cold trap per day would be available for mishandling such that its inventory could be discharged to the neutralization pit is conservatively estimated to be 0.1.

The basic human error probability for the first commission of this error based on Reference 4.2 is 5 E-02/demand. The probability that the operator would discharge a second metal cold trap to the pit in a month from this operation given that the first cold trap was erroneously discharged to the pit is $(5E\text{-}02)^2$ provided that the two events are independent. Similarly, the probability of an erroneous discharge of the third cold trap given discharge of the first two cold traps is $(5E\text{-}02)^3$ provided the events are independent. Accordingly, the probability of the thirtieth error given the first twenty-nine errors is $(5E\text{-}02)^{30}$ provided independence of the events. However, the events are not necessarily independent. The fact that the postulated error is repeated day after day may be a result of a common cause failure (e.g., inadequate training). Although the supervisor has repeated opportunities to discover the errors throughout the month, the probability of the errors going undiscovered for a period of a month given the potential for dependence between events is conservatively assumed to be 1.0 (i.e., no error identification by the supervisor) . Accordingly, the probability that this many metal cold traps are available for release and that more than 228.6 kgs (double the mass of one cold trap per day) U are discharged to the neutralization pit by this mishandling activity is 5 E-03.

As stated previously, it is not considered credible for large deposits of uranium to accumulate and settle to the bottom of the pit under the dynamic conditions of flow that exist in the pit. Table 1 lists the uranium concentrations measured in the C-712 pit over a period of 38 months. The empirical data verifies that uranium does not accumulate in the pit. On average, the amount of uranium that enters the pit during the day also leaves the pit. Based on the C-712 pit flow volume and the capacity of the pit, the water inventory of the pit changes completely every two to three days. Therefore, 33% of the uranium discharged to the pit from a mishandling activity would pass through the pit on a daily basis. However, for the purposes of this analysis it is conservatively assumed that 15% of the uranium discharged to the pit exits the pit daily. The uranium that accumulates in the pit can be determined as follows.

The uranium inventory added to the pit at the end of the first day is

$$M_1 = A,$$

where

A = uranium mass added during the day.

If f = the fraction of the uranium inventory that exits during the day, then the uranium inventory remaining in the pit at the end of day 2 is

$$M_2 = M_1(1-f) + A = M_1 r + A = Ar + A,$$

where

$r = 1 - f.$

The uranium inventory at the end of day 3 is

$$M_3 = M_2 r + A = Ar^2 + Ar + A.$$

The inventory mass at the end of day i is then

$$M_i = Ar^{i-1} + Ar^{i-2} + \ldots + Ar + A.$$

Multiplying the above equation by r and subtracting the result from the above equation results in

$$M_i - rM_i = A - Ar^i.$$

Solving for M_i gives

$$M_i = \frac{A(1-r^i)}{1-r}$$

with r = 1 −0.15 = 0.85 and I = 30 days, the mass accumulating in the pit from discharging two cold traps per day into the C-712 pit (A = 7.62 kg) is 50.4 kg.

6.3.3 TUBEWASH Event Tree Event

The TUBEWASH event models the probability that more than the NCSA limit of tubes require washing such that subsequent operator errors result in an excessive discharge of uranium to the neutralization pit. The controls described in Sect. 5.2 of reference 4.3 limit the operation of the tube wash system in Room 21 to 10 times per week with a maximum of 25 tubes per wash cycle. This system is routinely operated at approximately 60 % of this capacity or 150 tubes per week. Therefore, a total of 1075 tubes in one month is considered bounding. Assuming each tube washed contains the volumetric maximum of 55 grams of UF_6 (37.2 g U), the quantity of uranium permitted to be discharged to the neutralization pit each month is 40.0 kg U. This is a conservative estimate since most tubes are smaller holding less material and the operator collects the rinsate from the most contaminated initial wash operation and places it in the geometrically safe carboy. It is assumed that double the allowed amount, 80.0 kg from 2150 tubes, is discharged to the neutralization pit during the month in violation of the NCSA. As for the SAMPLE event tree event, it is conservatively assumed that only 15% of the uranium discharged to the pit exits the pit each day. Using the equation derived in Section 6.3.2 for determining uranium inventory remaining with A = 80 kg /30 days or 2.67 kg results in accumulation of 17.7 kg uranium. The TUBEWASH event models the probability that this many tubes are present in the tube wash facility such that human errors result in the operation of the tube wash system more than 10 times per week.

Since the operation is currently run at 60 % of the NCSA limit, the probability that there would be more than the NCSA limit of tubes to be washed was estimated to be 0.10. The basic human error probability of operating the tube wash system 11 times one week in violation of the NCS controls is 5 E-02 based on Reference 4.2. Although the supervisor has repeated opportunities to discover the error throughout the month, the probability of the error going undiscovered for a period of a month is conservatively assumed to be 1.0 in this analysis (i.e., no error identification by the supervisor). Accordingly, the probability that more than the NCSA limit of tubes would be available to be washed such that more than 40.0 kgs U could be discharged to the neutralization pit is 5 E-03. It should be noted that the tube wash system in Room 21 is routinely operated by different personnel than those that complete the cold trap hydrolyzation activity in Room 53. Therefore, no dependence between these operations is assumed in the model.

6.3.4 CYLWASH Event Tree Event

The CYLWASH event tree event models the probability that more than the NCSA limit of cylinders require washing such that subsequent operator errors result in an excessive discharge of uranium to the neutralization pit. The controls described in Sect. 5.2 of reference 4.3 limit the operation of the cylinder wash system in Room 21 to a maximum of 120 cylinders washed per month. The cylinder wash system is currently operated as cylinders are received and this throughput corresponds to 80% of the NCSA limit. A significant deviation that would result in more cylinders requiring washing than the NCSA limit permits is not anticipated. The probability that the number of cylinders that require washing exceeds the NCSA limit such that the mishandling described below can occur was conservatively estimated to be 0.10 based on an 80% operating capacity. Assuming that twice the NCSA limit of cylinders are washed (240) and that all the cylinders washed contain the maximum of 30 grams of UF_6 (20.3 g U) per Reference 4.1, the quantity of uranium in the waste discharged to the neutralization pit each month is 4.9 kg U. Although the maximum inventory of a cylinder to be washed is limited to 20.3 g uranium, it is unlikely but possible that a violation of the NCSA could occur such that a filled cylinder could be inadvertently placed in the cylinder washer. The CYLWASH event models human errors that result in the operation of the cylinder wash system 20 times per month with eleven cylinders at their maximum inventory for washing and the twelfth cylinder filled with uranium (i.e., 2.2 kg uranium). In the extremely unlikely event that one filled cylinder per cylinder wash cycle were placed in the washer, the monthly discharge to the neutralization pit would be 48.6 kg uranium. As for the previous two event tree events, it is conservatively assumed that only 15% of the uranium discharged to the pit exits the pit each day. Using the equation derived in Section 6.3.2 for determining uranium inventory remaining in the pit with A = 48.6 kg/30 days or 1.62 kg uranium results in accumulation of 10.7 kg uranium.

The basic human error probability of operating the cylinder wash system in violation of the NCS controls is 5 E-02 based on Reference 4.2. However, the cylinder wash system is operated by the same group of individuals that operate the tube wash system. Therefore, the dependence between the two operations must be addressed in the model. It is conservatively assumed that if an operator fails to operate the tube wash system correctly, that operator will have an increased probability of operating the cylinder wash system incorrectly. This is a conservative assumption since the operator is trained for each piece of equipment and there is a separate NCSA posting control for each piece of equipment. The posting provides the operator a daily reminder of the correct operation of that equipment. The basic human error probability of 5 E-02/demand was increased to 5 E-01/demand to account for the dependence between the two operations. The fact that the error must be repeated in order to exceed the maximum safe loading and that supervision fails to detect this error is considered extremely unlikely. Although the supervisor has repeated opportunities to discover the error, the probability of the error going undiscovered 10 times in a month is conservatively assumed to be 1.0 in this analysis (i.e, no error identification by the supervisor). Accordingly, the probability that more than the NCSA limit of cylinders could be washed such that more than 24.3 kgs U could be discharged to the neutralization pit is 5 E-02. It should be noted that the dependence between the tube wash and cylinder wash systems has been addressed by the event tree model.

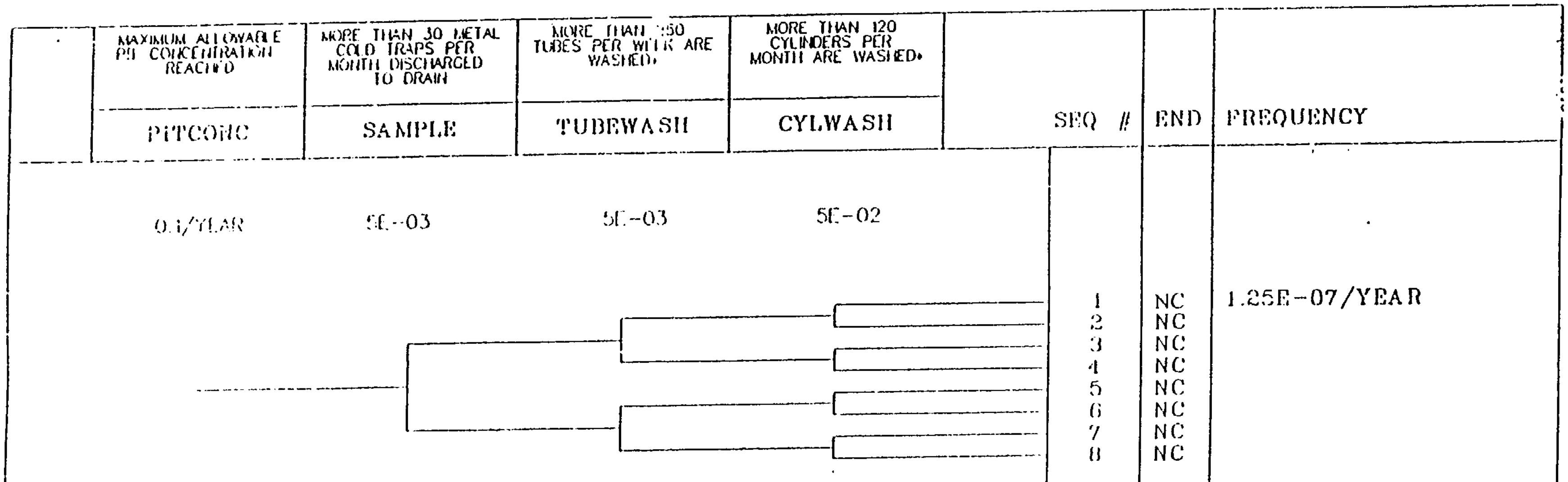
6.3.5 RESULTS

None of the postulated accident scenarios shown in the PITCRIT Event Tree results in a critical configuration. The worst case scenario involves a neutralization pit that equals or just exceeds the maximum allowable pit concentration of 0.34 grams ^{235}U per liter. In order for the pit to reach the mass of 146.1 kg uranium, the following errors must all occur within the same month:

- the contents of 60 metal cold traps which are normally refed to the cascade are erroneously discharged to the drain (228.6 kg U), 50.4 kg of which accumulates in the pit,

- the tube wash system is erroneously used to wash 500 tubes per week without collecting the rinsate from the initial wash in the month (80.0 kg U), 17.7 kg of which accumulates in the pit, and
- the cylinder wash system is erroneously used to wash 240 cylinders per month with one filled cylinder per each wash cycle (48.6 kg U), 10.7 kg of which accumulates in the pit.

The frequency of this accident scenario, shown in Fig. 3, is estimated to be 1.25E-07/year. Since this accident scenario involves the accumulation of 146.1 kg U in the pit, more than 3.9 kg U in additional discharges from other lab areas would have to occur near the same time to result in a critical configuration. The probability of such an occurrence is also unlikely which further reduces the calculated frequency of this event. The conservative approach taken in this evaluation assumed the pit to be filled with solution at its maximum permissible concentration of uranium. Also, only 15% of the postulated uranium discharged to the pit during a day is assumed to exit the pit even though empirical data demonstrates that on average the amount of uranium entering the pit also leaves the pit. It also took no credit for the supervisor discovering operator errors or the potential for the pit sampling analysis to identify a pit fissile concentration at the limit of 0.34 g ^{235}U/l. Based on this information and event tree analysis, a critical configuration due to the accumulation of uranium in the C-712 Neutralization Pit is not considered a credible event.



CC - CRITICAL CONFIGURATION

NC - NO CRITICAL CONFIGURATION (i.e. < 150 kg uranium)

* CONSIDERS PROBABILITY THAT SUFFICIENT NUMBER OF CONTAINERS ARE AVAILABLE FOR MISHANDLING TO OCCUR

Figure 3 PITCRIT Event Tree

7.0 Conclusion and Recommendation

A critical configuration due to the accumulation of uranium in the C-712 Neutralization Pit is not considered a credible event.

8.0 Approval

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