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NUCLEAR CRITICALITY SAFETY BOUNDING ANALYSIS FOR THE IN-TANK-PRECIPITATION (ITP) PROCESS (U)

BY
M. C. CHANDLER

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Michael C. Chandler — Date: 3/11/93
M. C. Chandler, Author
Manager HLWE Technology Studies

Charles E. Bess — Date: 3/11/93
C. B. Bess, Technical Reviewer

D. T. Hobbs — Date: 3/11/93
D. T. Hobbs, Technical Reviewer

J. E. Marra — Date: 3/12/93
J. E. Marra, Manager, HLW Engineering Support

B. G. Croley — Date: 3/12/93
B. G. Croley, Manager, ITP/ESP Engineering (Approved)

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DISCLAIMER

INTRODUCTION

The In-Tank Precipitation process (ITP) receives High Level Waste (HLW) supernatant liquid, commonly referred to as salt solution, containing radionuclides in waste processing tank 48H. Sodium tetraphenylborate, NaTPB, and monosodium titanate (MST), $NaTi_2O_5H$, are added for the removal of radioactive cesium and strontium, respectively. In addition to removal of radio-strontium, MST will also remove plutonium and uranium. The solids which contain the radioactive cesium and strontium are separated from the decontaminated supernate by filtration. The decontaminated supernate is transferred to tank 50H, which is the feed tank to Saltstone.

Sodium tetraphenylborate and MST are metered into the process tank and slurried by pumps with the salt solution. After filtration of the resulting slurry, fresh salt solution and NaTPB are added again and the process repeated two more times. After three process batches the tetraphenylborate and MST solids are washed, filtered, then transferred to the precipitate storage tank 49H. Later the slurry is transferred to the Defense Waste Processing Facility for incorporation into borosilicate glass.

The solutions fed to the ITP process are alkaline waste supernate, resulting from the neutralization of high level acidic waste generated in the Separations Canyon facilities. The majority of the feed solutions to ITP will come from the dissolution of crystallized salts that had been produced by evaporating and cooling the supernate liquid. The crystallized salt is commonly referred to as saltcake. Cesium is highly soluble in the supernate; whereas, strontium, uranium and plutonium are only slightly soluble. The concern for criticality safety arises from the adsorption of uranium and plutonium onto MST. Both uranium and plutonium have fissionable isotopes. If sufficient mass and optimum conditions are achieved then criticality is physically possible.

This report focuses solely on the accumulation of uranium and plutonium during ITP processing and precipitate storage. The concentration of uranium and plutonium from solution into the smaller volume of precipitate represents a possible concern for criticality. An extensive experimentation program was undertaken to define the physical and chemical properties of the sodium titanate and the uranium and plutonium solubility in ITP waste solutions. The results of the experiments in addition to criticality safety calculations provide the basis of the analysis in this report.

SUMMARY

Criticality safety in ITP can be analyzed by two bounding conditions; 1) the minimum safe ratio of MST to fissionable material and 2) the maximum fissionable material adsorption capacity of the MST. Calculations have provided the first bounding condition and experimental analysis has established the second. This report combines the two conditions evaluating the potential for criticality in the ITP process due to the adsorption of the fissionable material from solution. This report demonstrates that the potential for criticality due to adsorption of fissionable material by MST is incredible.

BACKGROUND

Accumulation Mechanism

The ITP process contacts HLW solutions with sodium tetraphenylborate and monosodium titanate to remove radioactive cesium and strontium. The concern for criticality safety arises from the adsorption of uranium and plutonium onto the monosodium titanate, the adsorbent agent for strontium. The settling of the material effectively concentrates any adsorbed uranium and plutonium into the volume of the settled mass. Since uranium and plutonium have fissionable isotopes*, the concentration and accumulation of the fissionable material is a possible concern for criticality safety.

MST is added during the first batch of a three batch ITP process cycle, and NaTPB is added every batch. Current plans are to add 0.3 grams of MST for every liter of solution to be decontaminated. This leads to approximately 1000 kilograms of MST added for every ITP process cycle.[1,2]

The criticality scenarios for ITP analyzed in this report involves first the accumulation of the fissionable material solids in eddies or mounds formed by agitation of the solids during mixing or liquid additions in the ITP processing tank 48H. The settling of the solids does not necessarily represent a criticality scenario. A homogeneous distribution of the fissionable material

* It is important to point out that when discussing chemical behavior, elemental names are referred to versus isotopes. As an example, all uranium isotopes behave chemically the same but only a few isotopes of uranium are fissionable, capable of causing a criticality, or fissile, capable of causing a criticality when moderated.

solids across the tank bottom would be within safe areal density limits.[3] However, the thin slab layer of solids on the tank bottom is uncontrolled and agitation will alter the geometry of the solids possibly producing a geometry of concern. The second scenario is the accumulation of multiple batches of precipitate in ITP tank 49H, the precipitate storage and feed tank to the Defense Waste Processing Facility.

To analyze these scenarios for criticality, an experimental program[4,5] was prepared to determine the capacity of the MST to adsorb both uranium and plutonium. The experiments covered a bounding range of MST concentrations and utilized the maximum solubilities for uranium and plutonium in the alkaline ITP solutions. These studies have provided loading equations for a range of MST concentrations. In addition, temperature effects were analyzed since during agitation the solution temperature will increase. The operating temperature is bounded by allowable corrosion control conditions.[6]

In addition to the experiments, nuclear criticality safety analysis calculations [7,8,9,10] have been performed to determine the safe bounding conditions for mixtures of MST and fissionable material. A major component of MST is titanium which is an effective neutron absorber and strongly influences the calculations. Initial k-infinite calculations evaluated an infinite mass of MST with varying fissionable material content. K-effective calculations evaluated the actual process condition of limited MST mass and variable fissionable material content. These calculations have also been used to define a conversion factor for plutonium to uranium [10] in the MST matrix to allow comparison of the fissionable isotopes to safe values.

In April of 1983 a full scale demonstration of ITP was completed.[11] The process was performed with salt solution from tank 24H. Very little plutonium was present in the solution though most was adsorbed onto the MST particles. Uranium was not tracked during the demonstration. Later analysis of the solids in the tank indicated the weight percent loading of uranium and plutonium to be much less than conditions evaluated in this report. The fissionable material loading was one tenth the infinite safe loading value of 1.96 wt% for ^{235}U.[12]

Fissionable Material

This report evaluates the criticality potential for uranium and plutonium, the most abundant fissionable elements in HLW. Other fissionable actinide elements, such as neptunium, americium, and curium, may also be present but are many times less abundant in HLW.

For the ITP process the fissionable elements/isotopes of concern are the fissile isotopes.*** The process involves solutions and solid slurries maintaining sufficient hydrogen present to allow the non-fissile but fissionable isotopes to be ignored.[13] In addition, there is sufficient hydrogen present in MST for this basis.[10] This eliminates the need to evaluate the criticality safety impact of many of the fissionable but non-fissile actinide isotopes/elements.

Americium and curium have fissile isotopes and are present in HLW. The mass of americium and curium in HLW is many times less than uranium and plutonium and the non-fissile isotopes greatly exceed the fissile isotopes.[14] The small mass of these elements entering the waste tanks is distributed throughout a few tanks. The soluble fraction of these elements would have been further distributed and diluted during evaporation operations involving; concentrate recycle and saltcake deposition. The very small contribution of americium and curium fissile isotopes to the much larger quantity of uranium and plutonium fissile isotopes led to these being ignored in this analysis. Sample analysis of ITP salt solutions and solids will allow continued confirmation of this assessment of americium and curium impact.

Uranium has two major fissile isotopes, ^{235}U and ^{233}U. Uranium in F-area HLW is predominantly depleted and natural uranium, (>99.2wt% ^{238}U), from plutonium production. In H-area the HLW contains enriched uranium due to losses in the HM process for recycled enriched uranium (waste has received up to 86wt% ^{235}U though mixing with lower enriched material reduces this value)[15,16,17,18]. A very small quantity of ^{233}U is also present from a few Thorex processing campaigns distributed between eight sludge tanks. In a salt tank, ^{233}U bearing supernate would have been blended with supernate from tanks of varying uranium enrichment when deposited as saltcake. As a result, the ^{233}U content of solution going to ITP is many times less than the ^{235}U content and is assumed to be represented by an equivalent ^{235}U in the analysis.[19]

Plutonium also has two fissile isotopes, ^{239}Pu and ^{241}Pu. Both isotopes are present due to plutonium process losses and as waste from recycled enriched uranium processing. In HLW, ^{241}Pu can be directly evaluated as ^{239}Pu. This is allowed when the ^{240}Pu content is greater than the ^{241}Pu due to the neutron adsorbing properties of ^{240}Pu competing with the fissioning of ^{241}Pu.[13,20]

*** Fissile - capable of undergoing fission by interaction with slow neutrons.

Safety Margins

This report conservatively evaluates the fissionable material by initially assuming 100% ^{235}U and 100% ^{239}Pu. The impact of decreasing the uranium ^{235}U isotopic percentage, or enrichment, is also determined to evaluate the margin of safety presented by the analysis.

An undetermined safety margin is provided by the precipitating agent for cesium, tetraphenylborate. The boron in the precipitating agent is an excellent neutron adsorber (isotope ^{10}B) and is present in varying concentrations during each process operation. Boron was ignored in the analysis because it's presence, or ratio to MST solids, cannot be guaranteed for certain steps of the process. Tetraphenylborate solids will be the greater fraction of solids in the ITP process versus MST. [1,2]

Another undetermined margin of safety in this analysis is the ability of the material to accumulate, particularly in the spherical geometry used in the calculational model. An incredible random event would have to occur for the required mass, volume and solids concentration to achieve the optimum spherical conditions for criticality.

ANALYSIS

The analysis utilizes data from the loading experiments and criticality safety calculations to define bounding conditions for the process. The first step in the analysis uses the safe MST loading values from the calculations to determine an expression for the safe maximum MST mass. The second step defines the maximum equivalent fissionable material loading** based on the experimental data and the plutonium to uranium conversion factor defined by the calculations. The maximum equivalent loading is then compared to the safe MST mass to evaluate the potential for criticality.

Safe Monosodium Titanate Fissionable Material Loading

The criticality safety analysis begins with the determination of the safe weight percent loading (or ratio) of uranium to MST for a given mass of monosodium titanate. K-infinite and k-effective calculations [8,9] defining

** The MST fissionable material loading is expressed as an equivalent ^{235}U wt% loading since in this analysis it represents the combined loading of fissionable isotopes converted to an equivalent ^{235}U wt% loading.

these values were based on assuming 100% ^{235}U. Each non-infinite MST mass value was conservatively evaluated as a sphere at optimum moderation conditions (H/U ratio). The data below is the basis for defining the relationship between the maximum safe fissionable material loading on MST and the maximum safe mass of MST.

Safe MST Mass	Safe U-235 Loading
Infinite	1.96 wt%
15,000 kg	2.2 wt%
2,400 kg	2.5 wt%
710 kg	2.9 wt%
570 kg	3.0 wt%

The safe mass and loading data can be fitted to logarithmic curve equations bounded by two ranges of MST mass.[10]

1) MST mass $\leq$ 2400 kg Safe eq ^{235}U wt% $= 6.618\ Y^{-0.125}$, Y = MST, kg

2) MST mass $\geq$ 2400 kg Safe eq ^{235}U wt% $= 4.303\ Y^{-0.07}$, Y = MST, kg

Throughout the remainder of the report the equation for the curve representing MST masses greater than 2400 kg is used. This curve is conservative for the range of values represented by equation 1) and does not impact the analysis.

Safe Maximum Accumulated Monosodium Titanate Mass

Since the accumulated monosodium titanate mass (Y) can vary for each criticality scenario being analyzed the equations defined above can be expressed in terms of the safe equivalent ^{235}U wt% (Z) by the following:

$$\text{Safe eq } ^{235}U \text{ wt\%} = Z = 4.303\ Y^{-0.07}, \text{ for MST mass} > 2400 \text{ kg}$$

Solving for the safe mass of MST gives,

3) $$Y = 10^{\text{Log}\,(4.303\ /\ Z)\ /\ 0.07} = \text{safe mass of monosodium titanate, kg}$$

If a fissionable material wt% loading is provided, expressed in terms of equivalent ^{235}U, the maximum safe mass of MST can be determined using equation 3) above. The value (Y) represents any MST mass added to the tank or an accumulation of MST mass depending on the scenario being evaluated.

Maximum Equivalent Uranium-235 Wt% Loading

Experiments on uranium and plutonium solubility and monosodium titanate adsorption were conducted to determine maximum bounding conditions for fissile material loading. Based on the resulting data and a plutonium to uranium conversion factor for the material matrix, the maximum equivalent ^{235}U wt% loading values were determined for any given monosodium titanate concentration****, or individual mass addition.

The conclusion of the experiments and criticality safety calculations determining a Pu-U conversion factor were as follows:

- The maximum uranium wt% loading on MST is defined by the equation $1.8 - 0.29(x)$, where (x) is the MST concentration in grams per liter. The equation represents a 3 σ confidence level and was determined for MST concentrations from 0.05 to 0.51 grams per liter.[4]

- The maximum plutonium wt% loading on MST is defined by the equation $0.29 - 0.20(x)$, where (x) is the MST concentration in grams per liter. The equation represents a 3 σ confidence level and was determined for MST concentrations from 0.05 to 0.51 grams per liter.[4]

- Uranium competes with plutonium for the limited adsorption sites on monosodium titanate. Uranium solubility is about an order of magnitude greater than plutonium in waste solutions.[21] Consequently at saturated uranium and plutonium concentrations, uranium loading will be greater than that of plutonium.

- The ^{239}Pu to ^{235}U conversion factor (V) is defined in terms of the total system or mass matrix being evaluated. The conversion factor is expressed by the equation $V = (2.3 - (9.0/\sqrt{(Y)}))$, where (Y) is the MST mass, kg, being evaluated.[10] If evaluating the criticality potential of a single MST mass addition (X) into the process tank then (Y) is equal to (X). When evaluating an accumulation of MST then (Y) represents the total accumulated mass being evaluated.

The maximum equivalent ^{235}U wt% loading is defined by,

4) Max. eq ^{235}U wt% = (wt% U on MST) + (V)(wt% Pu on MST)

**** MST concentration refers to the MST mass distributed in the ITP salt solution while agitated and well mixed.

Substituting for the maximum wt% loading of uranium and plutonium and the conversion factor for ^{239}Pu to ^{235}U gives,

$$\text{Max. eq } ^{235}U \text{ wt\%} = (1.8 - 0.29(x)) + (2.3 - 9.0/\sqrt{(Y)})(0.29 - 0.20(x))$$

The lower the concentration (x) used in the loading equations above gives the maximum wt% loading for plutonium and uranium. Therefore, assuming the MST addition mass (X) is distributed in the entire tank volume defines the maximum bounding eq ^{235}U wt% for equation 4). This is a conservative assumption since the actual process operating liquid volume is less than the maximum tank operating volume capacity of 1.3 million gallons.

$$(x), g/l = (X, kg)\ (1000\ g/kg) / ((1.3E6\ gallons)(3.785\ liters/gallon))$$

$$(x), g/l = 2.0E\text{-}4\ (X)$$

Incorporating this bounding condition results in the following,

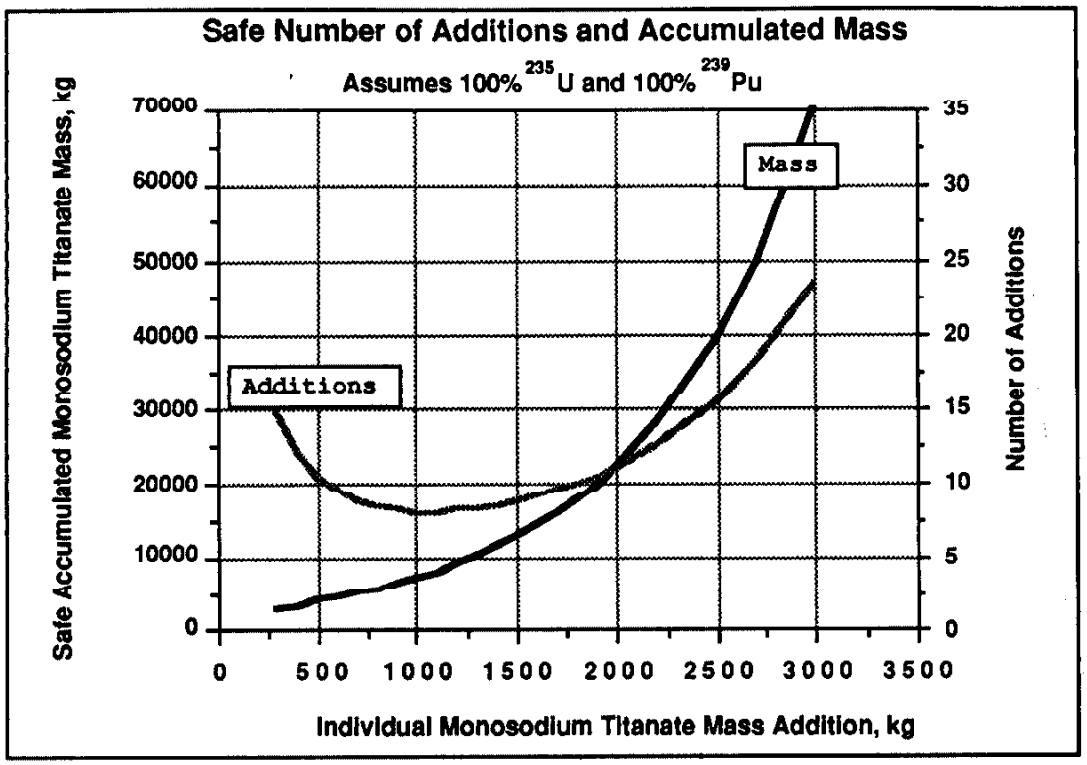
5) $$\text{Max. eq } ^{235}U \text{ wt\%} = (1.8 - 5.8E\text{-}5\ (X)) + (2.3 - 9.0/\sqrt{(Y)})(0.29 - 4.0E\text{-}5\ (X))$$

Maximum Eq U-235 wt% Loading to Safe Monosodium Titanate Mass

The maximum eq ^{235}U wt% loading determined by equation 5) can be used to determine the maximum safe mass of MST (Y) using equation 3). To perform the determination, an MST mass addition (X) is assumed defining the fissionable material loading using equation 5). Then the two equations can be solved for the remaining common variable, the maximum safe MST mass (Y). This is required due to the Pu-U conversion factor being dependent on the maximum or total MST mass being evaluated.

The graph below depicts the results of solving these equations for various MST mass additions (X). Also presented on the graph is the required number of MST mass additions (X) required to obtained the maximum safe MST mass (Y). A typical MST addition in the ITP process is expected to be approximately 1000 kg [1] (dependent upon the salt solution strontium content).

Example: A MST mass addition of 1000 kg could adsorb uranium and plutonium to an equivalent ^{235}U wt% loading value of 2.29 wt%. This ^{235}U wt% loading is safe for 8942 kg of MST as depicted in the graph. Since only 1000 kg of MST was added to the tank, at least eight (8) more additions of 1000 kg, each resulting in the same maximum equivalent ^{235}U wt% loading value of 2.29 wt%, is required before exceeding the safe allowable MST mass.



The spreadsheets used to develop the data displayed in the graph are contained in Attachment 1. An initial Pu-U conversion factor (V) is required to begin the calculation. The initial conversion factor allowed the determination of an initial equivalent ^{235}U wt% value using equation 5) for each MST addition (X). Next the maximum safe MST mass (Y) was defined using equation 3). This then allows a new Pu-U conversion factor (V) to be determined since the conversion factor is dependent on the total MST mass. This continues until convergence is reached, i.e. the maximum safe MST mass and conversion factor no longer change.

Criticality Scenario Discussion

For each MST mass addition, the fissionable material loading is defined by the MST mass concentration during processing. The distribution, or concentration, of the MST mass in the ITP salt solution provides the maximum chemical potential between the soluble fissionable material and the distributed MST particles. The actual ITP process involves allowing the MST particles to settle between process batches then repeating for two more batches, or contacts, with new salt solution. The loading of fissionable material, no matter how many contacts or batches of salt solution, remains

bounded by the chemical potential or relative concentration difference between the fissionable material in solution and MST distributed concentration. If good distribution of the MST in the liquid volume is not achieved then the relative MST concentration is greater and the fissionable material loading less, see 'Maximum Equivalent ^{235}U Wt% Loading' discussion above. After the three batches of salt solution, the precipitate is washed with inhibited water removing the remaining salt solution to Saltstone. The fissionable material loaded MST mass is then slurried and transferred to the precipitate storage tank 49H.

No individual addition of MST mass in the ITP process, per the graph above, represents a concern for criticality. The criticality scenario defaults to evaluating the potential for multiple additions of MST involved in multiple ITP process cycles accumulating. Accumulation does occur in ITP tank 49H where the ITP precipitate is stored before transfer to the Defense Waste Processing Facility. Accumulation could also occur in the ITP processing tank 48H if material was not completely removed between process cycles.

As indicated in the graph above, which assumes 100% fissile isotopic content of uranium and plutonium, a minimum of eight (8) MST mass additions is required before sufficient mass can accumulate representing conditions for criticality. Again this only indicates sufficient mass is present, not the required optimum geometry and moderation for criticality.

Tank 49H will receive and accumulate multiple batches of MST along with precipitate resulting from the added NaTPB. The anticipated process condition is to accumulate solids from six ITP process cycles, or six MST mass additions, in tank 49H. The bounding condition of assuming 100% fissile isotopes does not provide a sufficient margin of safety when comparing eight MST mass additions to the six anticipated. Since the maximum bounding scenario of assuming 100% fissile isotopes does not lead to a totally incredible condition, additional bounding conditions are evaluated.

Fissile isotopes are not 100% of the isotopes of uranium and plutonium present in the waste tanks. In the analysis below the impact of the non-fissile isotopes is determined. The non-fissile isotopes are conservatively evaluated as diluents only and not for their neutron absorption characteristics.

Uranium Enrichment Effect on Safe Values

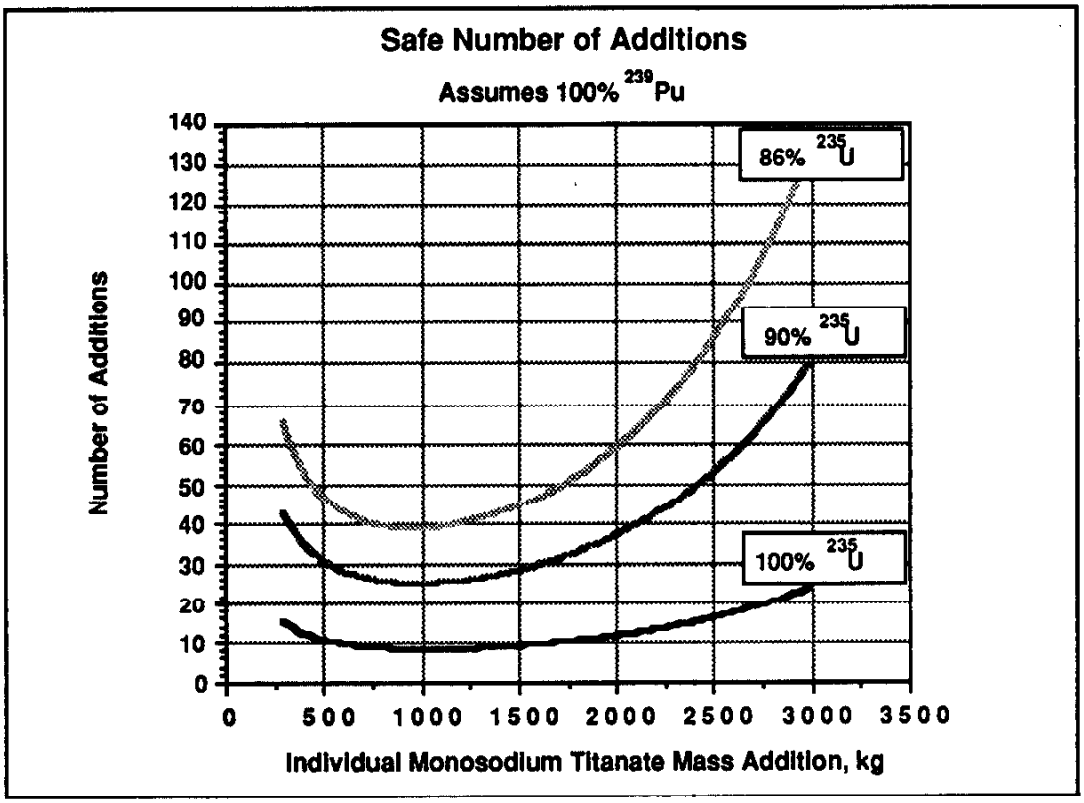
Uranium enrichment in SRS HLW is not 100% ^{235}U.[18] The uranium enrichment can be bounded by the maximum enrichment used at the site and from historical waste transfer data. In addition, the greater quantity of

depleted uranium in SRS HLW, less than 0.7 wt% ^{235}U, will greatly impact the analysis.[17] Incorporating the uranium enrichment values increases the required accumulated mass needed for criticality conditions demonstrated above and consequently the required number of MST mass additions.

Correcting equation 5) for uranium enrichment and solving similarly to the analysis above for various uranium enrichments results in the data demonstrated in the graph below. A similar analysis could be performed for plutonium; however, as demonstrated by the pronounced effect of uranium enrichment on the required number of MST mass additions, this is unnecessary. Data spreadsheets for this graph are contained in Attachment 1.

Equation 5) corrected for uranium enrichment results in the following,

$$\text{Max eq}^{235}\text{U wt\%} = (1.8 - 5.8\text{E-}5(X))(\text{wt\%}^{235}\text{U}) + (2.3 - 9.0/\sqrt{(Y)})(0.29 - 4.0\text{E-}5(X)))$$



As indicated by the graph above the percentage of fissile to non-fissile uranium isotopes (enrichment) has a significant impact on the potential for criticality. This was expected since any decrease in the uranium contribution

of fissile isotopes adsorbed by the MST requires an equal increase in the plutonium fissile mass/isotope contribution.

The highest uranium enrichment of waste sent to the waste tanks is bounded by a value of 86% ^{235}U.[18] Based on this bounding value, approximately 37 MST additions would be required to accumulate sufficient mass for criticality conditions. As indicated previously, the anticipated process condition is to accumulate solids from six ITP process cycles, or MST mass additions, in tank 49H. The required 37 MST additions for 86% ^{235}U provides a substantially larger safety margin versus the 8 MST additions assuming 100% ^{235}U.

No salt tank has received only 86% enriched uranium. The highest estimated enrichment value for a salt tank, 41H, is between 60% and 70%.[15,16] To empty a salt tank, it is estimated to require 3 to 4 ITP cycles. Assuming the estimate of 70% ^{235}U, the required number of MST additions is greater than 200 versus the 3 to 4 required to empty the tank.

The process plan is to alternate between H-area salt tanks and F-area salt tanks for saltcake removal. F-area waste consists of depleted and natural uranium; therefore, salt tanks receiving supernate from F-area tanks contain depleted and natural uranium. Once an F-area tank is process through ITP, and the MST accumulated with higher enriched uranium loaded MST, the required accumulated MST mass for criticality conditions increases significantly. Data spreadsheets in Attachment 1, pages 20 and 21, demonstrate the impact of decreasing enrichment values.

CONCLUSION

The analysis above demonstrates the application of the calculated k-effective data and MST uranium and plutonium loading experiments. The analysis provides bounding conditions for the criticality scenarios. For the extremely conservative case, assuming 100% ^{235}U , at least eight (8) MST mass additions are required before sufficient mass for criticality can accumulate.

The more realistic bounding enrichment case, 86% enriched uranium, requires at least thirty seven (37) MST mass additions. If ITP processes three cycles per year, then at least 12 years operation are required before sufficient mass for criticality can accumulate. Since most of the uranium contained in waste has an enrichment much less than 86% the required number of MST mass additions will greatly exceed thirty-seven (37). Based on these conditions criticality is deemed incredible since the number of MST additions required to accumulate sufficient fissionable material for criticality will exceed the number of ITP cycle operations required to empty the salt tanks.

It is also deemed incredible to assume the MST mass representing thirty-seven (37) mass additions, 37,000 kg, could accumulate as a sphere at the optimum mixture density, greater than 1750 grams per liter [9], for criticality.

ACTIONS

Process variables, actinide concentrations and isotopics, should be monitored throughout processing as a confirmation verification of the safety basis established by this report. The requirement for monitoring these variables should be identified in the ITP Process Requirements. This requirement should not be considered mandatory for process operations if the impact on personnel exposure and/or waste removal schedule is shown to be negative.

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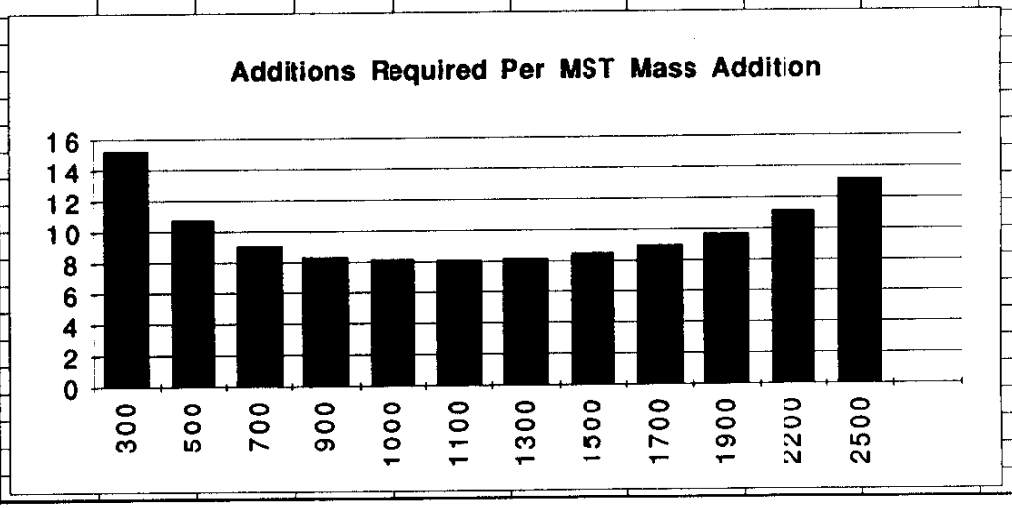
DATA SET FORMULAS

	A	B	C
1	MST Mass, Kg=	300	500
2	MST Conc, g/l=	=B1*1000/(1300000*3.785)	=C1*1000/(1300000*3.785)
3	U enrich=	0.95	=$B$3
4	U235 wt fraction=	=(1.8-0.29*B2)*B3	=(1.8-0.29*C2)*C3
5	Pu239 wt fraction=	=1	=$B$5
6	Pu wt fraction=	=(0.29-0.2*B2)*B5	=(0.29-0.2*C2)*C5
7	Pu239-U235=	2.25	2.25
8	eq U=	=B4+(B6*B7)	=C4+C6*C7
9	Safe Kg=	=10^((LOG(4.303/B8))/0.07)	=10^((LOG(4.303/C8))/0.07)
10	New Pu-U	=2.3-(9/SQRT(B9))	=2.3-(9/SQRT(C9))
11	New eqU=	=B$4+B$6*B10	=C$4+C$6*C10
12	New Safe Kg=	=10^((LOG(4.303/B11))/0.07)	=10^((LOG(4.303/C11))/0.07)
13	New' Pu-U	=2.3-(9/SQRT(B12))	=2.3-(9/SQRT(C12))
14	New' eqU=	=B$4+B$6*B13	=C$4+C$6*C13
15	New' Safe Kg=	=10^((LOG(4.303/B14))/0.07)	=10^((LOG(4.303/C14))/0.07)
16	New" Pu-U	=2.3-(9/SQRT(B15))	=2.3-(9/SQRT(C15))
17	New" eqU=	=B$4+B$6*B16	=C$4+C$6*C16
18	New" Safe Kg=	=10^((LOG(4.303/B17))/0.07)	=10^((LOG(4.303/C17))/0.07)
19	New"' Pu-U	=2.3-(9/SQRT(B18))	=2.3-(9/SQRT(C18))
20	New"' eqU=	=B$4+B$6*B19	=C$4+C$6*C19
21	New"' Safe Kg=	=10^((LOG(4.303/B20))/0.07)	=10^((LOG(4.303/C20))/0.07)
22	Batches=	=B21/B1	=C21/C1
23	Pu Mass, kg =	=B21*B6/100	=C21*C6/100
24	U Mass, kg =	=B21*(B$4/B$3)/100	=C21*(C$4/C$3)/100

ITP Data Set

MST Mass, Kg=	300	500	700	900	1000	1100	1300	1500	1700	1900	2200	2500
MST Conc, g/l=	0.061	0.1016	0.142	0.183	0.203	0.224	0.2642	0.3048	0.3455	0.3861	0.4471	0.5081
U enrich=	1	1	1	1	1	1	1	1	1	1	1	1
U235 wt fraction=	1.78	1.77	1.76	1.75	1.74	1.74	1.72	1.71	1.70	1.69	1.67	1.65
Pu239 wt fraction=	1	1	1	1	1	1	1	1	1	1	1	1
Pu wt fraction=	0.28	0.27	0.26	0.25	0.25	0.25	0.24	0.23	0.22	0.21	0.20	0.19
Pu239-U235=	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
eq U=	2.41	2.38	2.35	2.32	2.30	2.29	2.26	2.23	2.20	2.17	2.12	2.08
Safe Kg=	4011	4800	5758	6922	7597	8343	10080	12209	14827	18055	24386	33151
New Pu-U	2.16	2.17	2.18	2.19	2.20	2.20	2.21	2.22	2.23	2.23	2.24	2.25
New eqU=	2.38	2.36	2.33	2.30	2.29	2.28	2.25	2.22	2.19	2.16	2.12	2.08
New Safe Kg=	4672	5467	6425	7583	8252	8989	10699	12788	15346	18490	24639	33127
New' Pu-U	2.17	2.18	2.19	2.20	2.20	2.21	2.21	2.22	2.23	2.23	2.24	2.25
New' eqU=	2.38	2.36	2.33	2.30	2.29	2.28	2.25	2.22	2.19	2.16	2.12	2.08
New' Safe Kg=	4592	5394	6360	7526	8198	8939	10657	12752	15318	18470	24629	33127
New" Pu-U	2.17	2.18	2.19	2.20	2.20	2.20	2.21	2.22	2.23	2.23	2.24	2.25
New" eqU=	2.38	2.36	2.33	2.30	2.29	2.28	2.25	2.22	2.19	2.16	2.12	2.08
New" Safe Kg=	4601	5401	6366	7531	8202	8942	10660	12755	15320	18471	24629	33127
New"' Pu-U	2.17	2.18	2.19	2.20	2.20	2.20	2.21	2.22	2.23	2.23	2.24	2.25
New"' eqU=	2.38	2.36	2.33	2.30	2.29	2.28	2.25	2.22	2.19	2.16	2.12	2.08
New"' Safe Kg=	4600	5401	6365	7530	8202	8942	10659	12754	15319	18471	24629	33127
Batches=	15	11	9	8	8	8	8	9	9	10	11	13
Pu Mass, kg =	13	15	17	19	20	22	25	29	34	39	49	62
U Mass, kg =	82	96	112	132	143	155	184	218	260	312	411	547

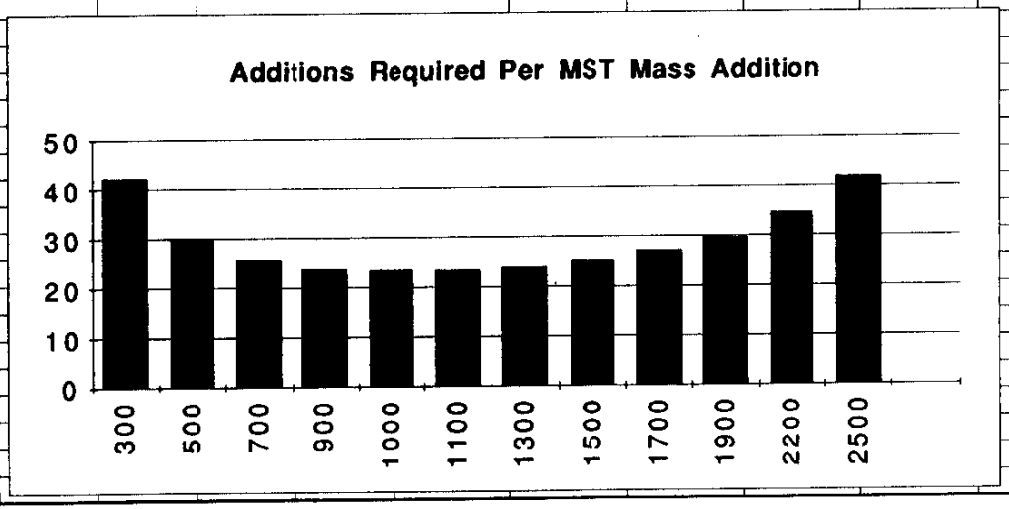
MST Mass Added	Added Number	Safe Mass
300	15	4600
500	11	5401
700	9	6365
900	8	7530
1000	8	8202
1100	8	8942
1300	8	10659
1500	9	12754
1700	9	15319
1900	10	18471
2200	11	24629
2500	13	33127



ITP Data Set

MST Mass, Kg=	300	500	700	900	1000	1100	1300	1500	1700	1900	2200	2500
MST Conc, g/l=	0.061	0.1016	0.142	0.183	0.203	0.224	0.2642	0.3048	0.3455	0.3861	0.4471	0.5081
U enrich=	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
U235 wt fraction=	1.60	1.59	1.58	1.57	1.57	1.56	1.55	1.54	1.53	1.52	1.50	1.49
Pu239 wt fraction=	1	1	1	1	1	1	1	1	1	1	1	1
Pu wt fraction=	0.28	0.27	0.26	0.25	0.25	0.25	0.24	0.23	0.22	0.21	0.20	0.19
Pu239-U235=	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
eq U=	2.23	2.20	2.17	2.14	2.13	2.11	2.08	2.06	2.03	2.00	1.95	1.91
Safe Kg=	12035	14502	17516	21212	23365	25753	31351	38270	46849	57517	78684	108401
New Pu-U	2.22	2.23	2.23	2.24	2.24	2.24	2.25	2.25	2.26	2.26	2.27	2.27
New eqU=	2.22	2.19	2.17	2.14	2.13	2.11	2.08	2.06	2.03	2.00	1.96	1.92
New Safe Kg=	12743	15144	18068	21639	23715	26014	31393	38028	46239	56437	76647	105000
New' Pu-U	2.22	2.23	2.23	2.24	2.24	2.24	2.25	2.25	2.26	2.26	2.27	2.27
New' eqU=	2.22	2.19	2.17	2.14	2.13	2.11	2.08	2.06	2.03	2.00	1.96	1.92
New' Safe Kg=	12691	15102	18036	21617	23697	26002	31391	38037	46259	56467	76694	105065
New" Pu-U	2.22	2.23	2.23	2.24	2.24	2.24	2.25	2.25	2.26	2.26	2.27	2.27
New" eqU=	2.22	2.19	2.17	2.14	2.13	2.11	2.08	2.06	2.03	2.00	1.96	1.92
New" Safe Kg=	12694	15105	18037	21618	23698	26003	31392	38036	46258	56466	76693	105064
New"' Pu-U	2.22	2.23	2.23	2.24	2.24	2.24	2.25	2.25	2.26	2.26	2.27	2.27
New"' eqU=	2.22	2.19	2.17	2.14	2.13	2.11	2.08	2.06	2.03	2.00	1.96	1.92
New"' Safe Kg=	12694	15104	18037	21618	23698	26003	31392	38036	46258	56466	76693	105064
Batches=	42	30	26	24	24	24	24	25	27	30	35	42
Pu Mass, kg =	35	41	47	55	59	64	74	87	102	120	154	198
U Mass, kg =	226	267	317	378	413	451	541	651	786	953	1281	1736

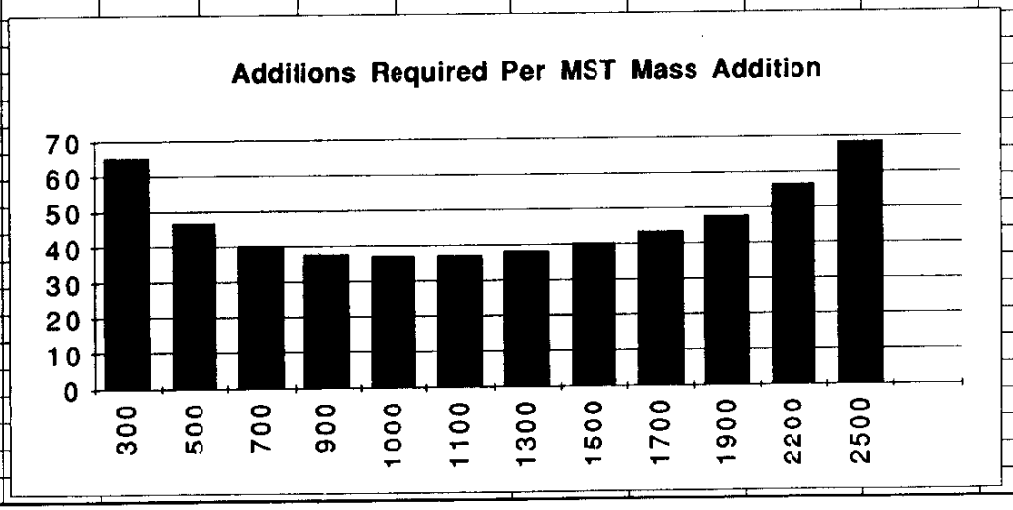
MST Mass Added	Added Number	Safe Mass
300	42	12694
500	30	15104
700	26	18037
900	24	21618
1000	24	23698
1100	24	26003
1300	24	31392
1500	25	38036
1700	27	46258
1900	30	56466
2200	35	76693
2500	42	105064



ITP Data Set

MST Mass, Kg=	300	500	700	900	1000	1100	1300	1500	1700	1900	2200	2500
MST Conc, g/l=	0.061	0.1016	0.142	0.183	0.203	0.224	0.2642	0.3048	0.3455	0.3861	0.4471	0.5081
U enrich=	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
U235 wt fraction=	1.53	1.52	1.51	1.50	1.50	1.49	1.48	1.47	1.46	1.45	1.44	1.42
Pu239 wt fraction=	1	1	1	1	1	1	1	1	1	1	1	1
Pu wt fraction=	0.28	0.27	0.26	0.25	0.25	0.25	0.24	0.23	0.22	0.21	0.20	0.19
Pu239-U235=	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
eq U=	2.16	2.13	2.10	2.07	2.06	2.04	2.02	1.99	1.96	1.93	1.89	1.85
Safe Kg=	19148	23142	28040	34065	37584	41495	50685	62087	76277	93992	129323	179236
New Pu-U	2.23	2.24	2.25	2.25	2.25	2.26	2.26	2.26	2.27	2.27	2.27	2.28
New eqU=	2.15	2.13	2.10	2.07	2.06	2.05	2.02	1.99	1.96	1.93	1.89	1.85
New Safe Kg=	19685	23529	28228	33991	37352	41083	49839	60635	74169	90989	124519	171888
New' Pu-U	2.24	2.24	2.25	2.25	2.25	2.26	2.26	2.26	2.27	2.27	2.27	2.28
New' eqU=	2.15	2.13	2.10	2.07	2.06	2.05	2.02	1.99	1.96	1.93	1.89	1.85
New' Safe Kg=	19653	23508	28219	33994	37361	41099	49867	60727	74224	91058	124609	172000
New" Pu-U	2.24	2.24	2.25	2.25	2.25	2.26	2.26	2.26	2.27	2.27	2.27	2.28
New" eqU=	2.15	2.13	2.10	2.07	2.06	2.05	2.02	1.99	1.96	1.93	1.89	1.85
New" Safe Kg=	19655	23509	28219	33994	37361	41098	49866	60726	74222	91056	124607	171998
New"' Pu-U	2.24	2.24	2.25	2.25	2.25	2.26	2.26	2.26	2.27	2.27	2.27	2.28
New"' eqU=	2.15	2.13	2.10	2.07	2.06	2.05	2.02	1.99	1.96	1.93	1.89	1.85
New"' Safe Kg=	19655	23509	28219	33994	37361	41098	49866	60726	74222	91056	124607	171998
Batches=	66	47	40	38	37	37	38	40	44	48	57	69
Pu Mass, kg =	55	63	74	86	93	101	118	139	164	194	250	324
U Mass, kg =	350	416	496	594	650	713	859	1039	1262	1537	2081	2843

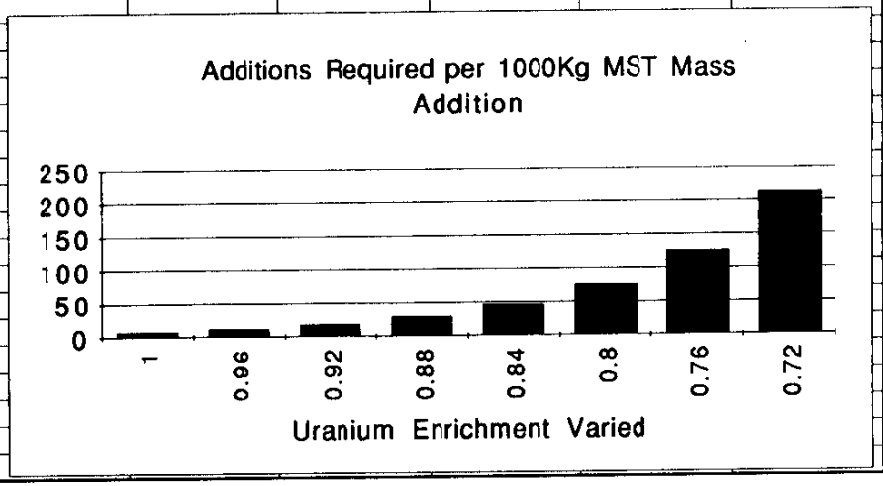
MST Mass Added	Added Number	Safe Mass
300	66	19655
500	47	23509
700	40	28219
900	38	33994
1000	37	37361
1100	37	41098
1300	38	49866
1500	40	60726
1700	44	74222
1900	48	91056
2200	57	124607
2500	69	171998



ITP Data Set

MST Mass, Kg=	1000	1000	1000	1000	1000	1000	1000	1000
MST Conc, g/l=	0.203231	0.203231	0.203231	0.203231	0.203231	0.203231	0.203231	0.203231
U enrich=	1	0.96	0.92	0.88	0.84	0.8	0.76	0.72
U235 wt fraction=	1.74	1.67	1.60	1.53	1.46	1.39	1.32	1.25
Pu239 wt fraction=	1	1	1	1	1	1	1	1
Pu wt fraction=	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Pu239-U235=	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
eq U=	2.30	2.23	2.16	2.09	2.02	1.95	1.88	1.81
Safe Kg=	7597	11782	18529	29575	47957	79094	132835	227493
New Pu-U	2.20	2.22	2.23	2.25	2.26	2.27	2.28	2.28
New eqU=	2.29	2.22	2.16	2.09	2.03	1.96	1.89	1.82
New Safe Kg=	8252	12419	19028	29692	47212	76543	126640	214035
New' Pu-U	2.20	2.22	2.23	2.25	2.26	2.27	2.27	2.28
New' eqU=	2.29	2.22	2.16	2.09	2.03	1.96	1.89	1.82
New' Safe Kg=	8198	12376	19001	29687	47239	76617	126783	214279
New" Pu-U	2.20	2.22	2.23	2.25	2.26	2.27	2.27	2.28
New" eqU=	2.29	2.22	2.16	2.09	2.03	1.96	1.89	1.82
New" Safe Kg=	8202	12379	19002	29687	47238	76615	126779	214275
New"' Pu-U	2.20	2.22	2.23	2.25	2.26	2.27	2.27	2.28
New"' eqU=	2.29	2.22	2.16	2.09	2.03	1.96	1.89	1.82
New"' Safe Kg=	8202	12379	19002	29687	47238	76615	126779	214275
Batches=	8	12	19	30	47	77	127	214
Pu Mass, kg =	20	31	47	74	118	191	316	534
U Mass, kg =	143	216	331	517	822	1334	2207	3731

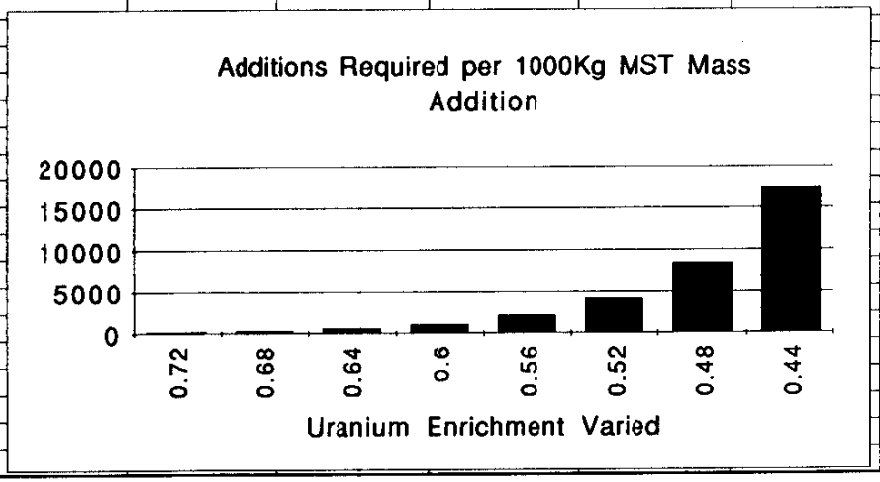
Uranium Enrichment	Added Number
1	8
0.96	12
0.92	19
0.88	30
0.84	47
0.8	77
0.76	127
0.72	214



ITP Data Set

MST Mass, Kg=	1000	1000	1000	1000	1000	1000	1000	1000
MST Conc, g/l=	0.203231	0.203231	0.203231	0.203231	0.203231	0.203231	0.203231	0.203231
U enrich=	0.72	0.68	0.64	0.6	0.56	0.52	0.48	0.44
U235 wt fraction=	1.25	1.18	1.11	1.04	0.97	0.91	0.84	0.77
Pu239 wt fraction=	1	1	1	1	1	1	1	1
Pu wt fraction=	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Pu239-U235=	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
eq U=	1.81	1.74	1.68	1.61	1.54	1.47	1.40	1.33
Safe Kg=	227493	397894	711962	1305800	2460247	4773614	9565890	19863080
New Pu-U	2.28	2.29	2.29	2.29	2.29	2.30	2.30	2.30
New eqU=	1.82	1.75	1.69	1.62	1.55	1.48	1.41	1.34
New Safe Kg=	214035	369972	655000	1189661	2221053	4272000	8487633	17472911
New' Pu-U	2.28	2.29	2.29	2.29	2.29	2.30	2.30	2.30
New' eqU=	1.82	1.75	1.69	1.62	1.55	1.48	1.41	1.34
New' Safe Kg=	214279	370369	655629	1190646	2222594	4274422	8491483	17479126
New" Pu-U	2.28	2.29	2.29	2.29	2.29	2.30	2.30	2.30
New" eqU=	1.82	1.75	1.69	1.62	1.55	1.48	1.41	1.34
New" Safe Kg=	214275	370363	655621	1190637	2222583	4274409	8491468	17479108
New"' Pu-U	2.28	2.29	2.29	2.29	2.29	2.30	2.30	2.30
New"' eqU=	1.82	1.75	1.69	1.62	1.55	1.48	1.41	1.34
New"' Safe Kg=	214275	370364	655621	1190637	2222583	4274409	8491468	17479108
Batches=	214	370	656	1191	2223	4274	8491	17479
Pu Mass, kg =	534	924	1635	2969	5542	10658	21174	43585
U Mass, kg =	3731	6448	11415	20730	38697	74420	147842	304322

Uranium Enrichment	Added Number
0.72	214
0.68	370
0.64	656
0.6	1191
0.56	2223
0.52	4274
0.48	8491
0.44	17479



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