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ASSESSMENT OF NUCLEAR SAFETY AND NUCLEAR CRITICALITY POTENTIAL IN THE DEFENSE WASTE PROCESSING FACILITY (U)

by

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**ASSESSMENT OF NUCLEAR SAFETY AND NUCLEAR
CRITICALITY POTENTIAL IN THE DEFENSE WASTE
PROCESSING FACILITY (U)**

Summary

The S-Area Defense Waste Processing Facility (DWPF) will initially process Batch 1 sludge¹ in the sludge-only processing mode, with

simulated non-radioactive Precipitate Hydrolysis Aqueous (PHA) product, without the risk of nuclear criticality. The dilute concentration of fissile material in the sludge combined with excess of neutron absorbers during normal operations make criticality throughout the whole process incredible.

Subsequent batches of the DWPF involving radioactive precipitate slurry and PHA will require additional analysis. Any abnormal or upset process operations, which are not considered in this report and could potentially separate fissile material, must be individually evaluated. Scheduled maintenance operation procedures are not considered to be abnormal.

Introduction

The Savannah River Site (SRS) High Level Nuclear Waste will be vitrified in the S-Area Defense Waste Processing Facility (DWPF) for long term storage and disposal. Since the S-Area feed streams contain uranium and plutonium, the S-Area process must be evaluated to ensure subcriticality is maintained. This is an assessment of nuclear safety issues and potential sources of nuclear criticality incidents in the S-Area vitrification process.

High level waste salt solution is processed in the Tank Farm In-Tank Precipitation (ITP) process to remove cesium-137 and to adsorb strontium on monosodium titanate (MST). Uranium and plutonium are also adsorbed on MST.² The tetraphenylborate slurry containing potassium and cesium tetraphenylborate precipitates and MST with adsorbed strontium, uranium, and plutonium is then washed in the DWPF Late Wash Facility (LWF) before fed to the DWPF Salt Processing Cell (SPC).

In the Salt Processing Cell, the precipitate slurry is first stored in the Precipitate Reactor Feed Tank (PRFT) and then processed in the Precipitate Reactor (PR). In the PR, tetraphenylborate is destroyed by acid hydrolysis reactions to produce benzene and an aqueous phase containing radionuclides.

The alkaline sludge slurry is transferred from Tank Farm Extended Sludge Processing operation to the Sludge Receipt and Adjustment Tank (SRAT) in the DWPF Chemical Processing Cell (CPC). The sludge slurry is treated with nitric acid in the SRAT to control the

rheological properties of the sludge slurry and to react with several components on the slurry, primarily nitrites and carbonates.

The Precipitate Hydrolysis Aqueous (PHA) product is combined with the sludge slurry and the borosilicate glass frit in the DWPF Chemical Process Cell (CPC) to produce a melter feed. The high level radioactive waste is finally immobilized in a glass matrix contained in sealed stainless steel canisters.

This report assesses the S-Area DWPF process starting from the receipt of slurry feeds in the Low Point Pump Pit Precipitate Tank (LPPPT) and the Low Point Pump Pit Sludge Tank (LPPST), and continuing through the whole S-Area DWPF processes.

Following is a discussion of each of the areas and processes of the DWPF in terms of potential nuclear safety issues and nuclear criticality concerns.

S-Area DWPF Feed Slurries

The slurry feeds from Tank Farm to the DWPF are inherently safe with respect to nuclear criticality because of low concentrations of fissile materials and sufficient neutron poisons.^{3,4} The DWPF precipitate and sludge feeds are discussed further in following sections. However, this fact is mentioned first to allow the possibilities of accumulation of fissile material in piping and transfer systems to be ignored. Unless a mechanism exists to separate fissile material from the bulk solids (precipitate and sludges), nuclear criticality is considered impossible. Throughout this report, only process areas, in which chemical and physical interactions might separate fissile materials from bulk solids that could then accumulate in a configuration which could cause a nuclear criticality incident, are considered.

DWPF Precipitate Feed

The precipitate slurry feeds from Tank Farm to the DWPF are inherently safe with respect to nuclear safety and nuclear criticality. Chandler³ demonstrated that the potential for criticality due to adsorption of fissionable material by MST is incredible. He analyzed criticality safety in ITP 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. The first bounding condition was evaluated using calculations. The second bounding condition was determined by experimental analysis.

Reference 3 documented that the maximum loading of uranium and plutonium on monosodium titanate (MST) is below the individual infinitely safe limits for plutonium and uranium. Therefore, as long as there is no mechanism to separate uranium and plutonium from MST substrate, leading to an accumulation of the fissile materials, the precipitate feed and its subsequent process streams are subcritical.

DWPF Sludge Feed

The sludge slurry feeds from Tank Farm to the S-Area are also inherently safe with respect to nuclear safety and nuclear criticality for the first four sludge batches. Clemmons⁴ concluded that the contents of Tank 42 and 51, S-Area Batch 1 sludge, are safe with respect nuclear criticality because of the dilute concentration of fissile material in the sludge combined with excess of neutron absorbers.

Sludge feed from Batch 2 through 4 can also be demonstrated to be safe using Clemmons⁴'s methodology. There is an abundance of neutron absorbing materials in sludge feeds, specifically iron (Fe) and manganese (Mn). To take credit for the neutron absorbing properties of Fe and Mn, they must remain in the process streams throughout the S-Area DWPF process. The abundance of Fe and Mn in the first four DWPF batches are documented by Fowler.⁵⁻⁸ Reference 1 also contains the most recent data on Batch 1 composition. Throughout the S-Area DWPF process, iron essentially remains insoluble throughout normal process operations. However, 50 percent of manganese is expected to dissolve during acid treatment in the Slurry Receipt and Adjustment Tank (SRAT) process.⁹ Choi also showed an abundance of Fe and Mn throughout his material balance of DWPF processing Batch 1 sludge.¹

In Table 1, the weight ratios of Fe and Mn to Pu-239 and U-235 found in DWPF sludge batch 1 are compared to calculated safe weight ratios¹⁰⁻¹¹. Two columns are used to represent the composition data of Batch 1. The first column represents experimental analysis of Tank 42 and Tank 51, which will be combined to form DWPF Batch 1 sludge feed. The second column represents data estimated from

accountability data and are known to have questionable accuracy. Clemmons argued that although a documented fissile equivalency between U-235 and Pu-239 has not yet been published, the excessive margin of safety with these high ratios allows a simplistic conservative equivalency model to be used.⁴ Safe weight ratios of Fe and Mn to Pu-239 are greater than the safe weight ratios of Fe and Mn to U-235¹⁰⁻¹¹, respectively. It is reasonable to assume that when U-235 and Pu-239 exist together, the safe weight ratios of Fe and Mn to this combination will be no greater than for an equal proportion of Pu-239. Using this argument, the existing Fe and Mn to equivalent Pu-239 (U-235 + Pu-239) weight ratio is much greater than the infinite safe values, about 4 times. Applying only Fe and Mn safe weight ratio is conservative since no credit is taken for several other diluents in the sludge feed that are significant neutron absorbers.^{1,5-8,12-13}

Table 1. Comparisons of Fe and Mn to U-235 and Pu-239 Weight Ratios vs Calculated Safe Weight Ratios for DWPF Batch 1.

<u>Absorber to Fissiles</u>	<u>Batch 1¹²⁻¹³ Wt Ratio</u>	<u>Batch 1⁵ Wt Ratio</u>	<u>Safe Wt.¹⁰⁻¹¹ Ratios</u>
Fe/U-235	1445:1	2600:1	77:1
Mn/U-235	192:1	474:1	30:1
Fe/Pu-239	3465:1	4007:1	160:1
Mn/Pu-239	460:1	730:1	32:1
Fe/Eq. Pu-239*	1019:1	1577:1	160:1
Mn/Eq. Pu-239*	135:1	287:1	32:1

*All U-235 assumed to be Pu-239 for comparison to safe Pu-239 weight ratios.

In Table 2, the weight ratios of Fe and Mn to Pu-239 and U-235 found in DWPF sludge batch 2 through 4 are compared to calculated safe weight ratios¹⁰⁻¹¹. The composition data were estimated from accountability data. From Table 1, the biggest difference of the ratios from experimental data is about 50% of the accountability data for the manganese to equivalent plutonium. Using the same argument as above, Batch 3 represents the worst sludge feed which has twice

the weight ratio of Fe and Mn to equivalent Pu-239 (U-235 + Pu-239) infinite safe values. If the accountability data underestimates the amount of fissile material by 50 % as in batch 1, DWPF Batch 3 sludge feed is still within the safe weight ratio. It is also worth mentioning that only DWPF Batch 1 feed composition is currently known with any certainty. Before a sludge batch is ready to be transferred to the DWPF, the same analysis will be performed to evaluate nuclear safety of that sludge batch by the Tank Farm. This type of analysis is also conservative since it ignores the contribution of other diluents in the the sludge feed that are significant neutron absorbers, such as Al, U-238, Mg, Ni, Cr, and Hg.^{1,5-8,12-13}

Table 2. Comparisons of Fe and Mn to U-235 and Pu-239 Weight Ratios vs Calculated Safe Weight Ratios for DWPF Batch 2 through 4.

<u>Absorber to Fissiles</u>	<u>Batch 2⁶ Wt Ratio</u>	<u>Batch 3⁷ Wt Ratio</u>	<u>Batch 4⁸ Wt Ratio</u>	<u>Safe Wt.¹⁰⁻¹¹ Ratios</u>
Fe/U-235	866:1	521:1	953:1	77:1
Mn/U-235	146:1	93:1	286:1	30:1
Fe/Pu-239	1427:1	1400:1	2112:1	160:1
Mn/Pu-239	242:1	251:1	635:1	32:1
Fe/Eq. Pu-239*	539:1	380:1	656:1	160:1
Mn/Eq. Pu-239*	91:1	68:1	197:1	32:1

*All U-235 assumed to be Pu-239 for comparison to safe Pu-239 weight ratios.

As mentioned earlier, iron remains essentially insoluble throughout the whole DWPF processes during normal operation. About 50% of manganese is expected to be dissolved during the SRAT reaction cycle.⁹ As long as the Fe and Mn to fissile material weight ratios are maintained in excess of the calculated safe weight ratios, all processes involving sludges are critically safe.

The only process area where nuclear criticality may still be an issue is in the Salt Processing Cell. However, for Batch 1 sludge-only operation, the Salt Processing Cell will process nonradioactive

simulants, and therefore it can be concluded the whole S-Area DWPF process during sludge-only operation is critically safe.

Low Point Pump Pit Precipitate Tank (LPPPPT), Low Point Pump Pit Sludge Tank (LPPPST), Piping and Slurry Transfer Systems

There is no known physical or chemical mechanism for separation of fissile material from the bulk solids (precipitate and sludges) in these systems. Nuclear criticality is considered to be impossible in these systems and subsequent piping and slurry transfer systems. Therefore, they are inherently safe, with respect to nuclear criticality, because the bulk solids are inherently safe. Nuclear criticality is not an issue in the LPPPPT, the LPPPST or the piping and related transfer systems.

Late Wash Facility (LWF)

The Late Wash Facility will not be in operation to process radioactive precipitate slurry feed from Tank Farm during Batch 1 sludge processing. Therefore, it would not affect the conclusion that process operation is critically safe during S-Area sludge-only processing of Batch 1 sludge feed.

However, the Late Wash Facility be analyzed for nuclear safety before the LWF is scheduled to receive the first radioactive precipitate feed. Of particular concern is the filtration system where solids are accumulated. Analysis must show that either (1) fissile material will not be separated from the bulk solids, either chemically or physically; or (2) if separation and accumulation does occur, nuclear criticality is impossible due to unfavorable geometry or other factors.

The analysis of the Late Wash Facility will be similar to that of the In-Tank Precipitation's filtration system, and would use the same sources of information.

Salt Process Cell (Precipitate Hydrolysis Process)

The Precipitate Hydrolysis Process (PHP) is one of the places where chemical reactions and processes could potentially separate and accumulate fissile material in an unsafe configuration, with respect to nuclear criticality. The precipitate slurry fed to the Salt Process Cell

poses no nuclear safety concern in the form delivered from the waste tanks³. As documented in reference 3, the maximum loading of uranium and plutonium on monosodium titanate (MST) is below the individual infinitely safe limits for plutonium and uranium. However, the MST may be altered by the process reaction conditions and uranium and plutonium may not remain bound to the MST. Experiments are currently being performed to determine if uranium and plutonium would remain bound to MST throughout the precipitate hydrolysis reaction cycle. Once the behavior of uranium and plutonium adsorbed on MST is established for the Precipitate Reactor's (PR) conditions, a complete nuclear safety evaluation will be performed.

Following is a discussion of nuclear safety concerns which will be applicable when the Salt Processing Cell is processing radioactive material. The contents of the precipitate reactor feed tank (PRFT) is always safe, because of the inherent safety of the precipitate slurry before any processing is done. For the following cases where there may be potential nuclear incidents, it is assumed that there will be no isotopic separation, and hence no isotope enrichment. The bounding cases of these scenarios will be analyzed and documented by a certified nuclear criticality specialist.

(1) Fouling

In this scenario, the precipitate hydrolysis reactions have gone in unexpected directions, and significant fouling of the cooling coils in the PR by tars has occurred. The fissile material, mainly uranium and plutonium, is assumed to be distributed uniformly on the coils in the precipitate hydrolysis reactor (PR). Since this situation happened in the previous reference HAN process where four precipitate hydrolysis batches were processed before fouling was discovered, the total amount of fissile material will be assumed to be an accumulation of four batches.¹⁴ Fouling is not thought possible under the current late washing precipitate hydrolysis process. It will be used as the worst case scenario, as an upset or abnormal condition which could be monitored and detected by tracking of the heat transfer coefficient of the PR cooling coils¹⁵.

(2) Accumulation of Fissile Material due to Loss of Agitation.

In this scenario, fissile material separates from MST and settles at the bottom of the PR or Precipitate Hydrolysis Bottoms Tank (PRBT). Agitation was lost at the end of one batch, fissile material settles uniformly to the bottom of these tanks with other solids, and another batch has been transferred into the vessel, causing accumulation of two batches of fissile material. It is believed that total amount of fissile material in two PR batches (and also two PRBT batches), will not cause a nuclear safety concern. A nuclear safety analysis may be performed to determine if the geometry of the PR and PRBT is inherently safe, or if the total amount of fissile material in 2 PR batches can cause a nuclear safety concern.

The total number of PR and PRBT batches that could cause a concern about accumulating a critical mass of fissile material due to loss of agitation will also be determined and documented. This study will provide a technical basis. However, this scenario is not credible, since loss of agitation is a process upset condition that would be detected before processing of more than two batches is completed.

(3) Accumulation of Fissile Material in Sump.

Process leaks, spills, and floor flushes in the Salt Process Cell (SPC) are collected in sump collection systems. Both aqueous and organic solutions will be collected. The remote sump pump ordinarily discharge to the PR to prevent the spread of organics outside the SPC. A direct jumper route from the sump pump to the Formic Acid Waste Header and the Hot Decontaminated Waste Header is also provided for future use if necessary. This direct jumper will discharge the sump into the Recycle Collection Tank (RCT).

In the worst case scenario the entire contents of both the PR and the PRFT are discharged onto the floor and collected in the sump. A nuclear criticality incident is not expected to be possible, based on the total amount of fissile material in these two tanks.

For the scenario where solid material accumulates in the sump over time, there is a lot of uncertainty and not enough information. The total number of PR and/or PRFT batches that would have to be spilled over a period of time to accumulate a

critical mass in the sump will be determined to form a basis for later assessment. Two years of precipitate hydrolysis feed, which is approximately equivalent to a sludge batch, will be used as the upper bound in these calculations.

(4) Accumulation in Condenser/Decanter

During the steam distillation portion of the precipitate hydrolysis reaction cycle, an equivalent of 4 lbs of water per pound of insoluble solids fed to the reactor is evaporated into the Precipitate Hydrolysis Condenser Decanter (PRCD). Aqueous flows from the decanter (PRCD) back to the reactor; and organic overflows to the Organic Evaporator (OE).

Accumulation of fissile material in the PRCD was thought possible due to steam stripping and entrainment. This concern was discussed but no nuclear safety concern was identified. The amount of fissile material in one PR batch is small as will be confirmed by calculation in item 1 above. Accumulation of fissile material in the PRCD is also thought not possible for more than 1 batch. At the end of the PR cycle, all of the material would be returned to the PR.

(5) Accumulation in the Organic Evaporator

Organic materials collected in the OE are recirculated to the PRCD to remove heavy organics collected during steam distillation. After precipitate reactor operation is complete, the organic-water mixture is mixed with high speed agitation to extract radionuclides, primarily Cs-137, from the organics prior to evaporation. Eventually, the aqueous will be returned to the PR at the end of the OE cycle via the PRCD.

Some fissile material may reach the OE. However, this concern is bounded by the previous concern in the PRCD, and fissile material will eventually end up in the PR.

(6) Decontamination Route.

This is not a concern since material in the SPC sump is expected to be transferred to the PR for processing. In the case where the sump content is routed to the RCT, worst case scenarios

considered in the sump (item 3 above) are expected to be the bounding cases.

Chemical Process Cell

A worst case scenario in the Slurry Mix Evaporator (SME) is already documented.¹⁶ Following are nuclear criticality concerns in the Chemical Process Cell, in particular, the SRAT vessel, which have been evaluated for DWPF Batch 1 composition.¹⁷

- (1) Processing streams representing the start of the SRAT reaction cycle (the sludge feed) and the end of the SRAT cycle (the SRAT to SME transfer stream) are shown to be inherently safe with respect to nuclear criticality during normal operating conditions.¹⁷ The uranium and plutonium contents in these streams are treated as U_3O_8 at 100% U-235 isotopes and PuO_2 at 100% Pu-239 isotope in the nuclear safety evaluation¹⁷. The infinite multiplication factor for a very large system (with no neutron leakage), or $K_{infinite}$, was shown to be less than 0.1 for both of the SRAT and SME feed streams. The Salt Cell Feed was also calculated but will have no bearing on these conclusions because that stream will be non-radioactive during Batch 1 operation.

The fissile content in the SRAT process is sufficiently dilute so that criticality is not a problem during normal operation, in which the sludge solids are completely suspended in the aqueous solution. This can also be interpreted that if the solids are completely dissolved in aqueous solution, nuclear criticality is incredible.

- (2) To represent settling of solids in the SRAT, the analysis of the solid mixtures in a range of dilution from full water, about 90% by weight, to less than 1% water. It was assumed that the metal oxides U_3O_8 , PuO_2 , Al_2O_3 , Fe_2O_3 , and MnO_2 remain in the same ratio as in the insoluble portion of the feed. It was shown that the system maintains a multiplication factor of less than 0.92 as long as the U-235 weight percent in uranium remains below 20%. Batch 1 sludge feed contains uranium with less than 1 % by weight U-235.^{3,12-13}

When K_{∞} is less than the safe value of 0.92, the system remains subcritical no matter what geometry the fissile material may assume. The result confirms the conclusion that the sludge feed is inherently safe. Settling and accumulation of sludge solids in process piping and transfer lines pose no nuclear criticality problem, unless the sludge composition is changed due to selective chemical dissolution of significant neutron absorbers, such as Fe, Mn, Al, U-238, Mg, Ni, Cr, and Hg, and leave uranium and plutonium solids behind. During normal operations, including scheduled maintenance operations, there is no known separation mechanism which will effectively remove all of the significant neutron absorbers without also removing uranium and plutonium.

Using only Fe and Mn, which are abundant in the sludge feed, ratios to fissiles, the same conclusion that Batch 1 sludge is nuclear safe is also reached. Available data for DWPF Batch 2 to 4 sludge feed compositions also indicated that nuclear criticality is incredible for the sludge feed. Again, the reasons are because of the abundance of Fe and Mn as shown in the DWPF Sludge Feed section.

- (3) Since the SRAT vessel is large, no assumption has been made about finite geometry. If the material is safe without finite geometry corrections,¹⁷ it is concluded that it would also be safe if the tank were to leak and its contents fall to the floor or down the sump.
- (4) There was a concern that plutonium oxide may be dissolved in the mercury in the mercury trap in the SRAT.¹⁸ It was postulated that plutonium could accumulate over time in the mercury trap, and cause a nuclear safety concern. This question was raised in reference 18 and was resolved experimentally¹⁹.

The distribution of plutonium was experimentally determined between the aqueous sludge slurry phase and the mercury phase using both simulated sludge doped with known amount of plutonium and Tank 42 sludge. It was found that the plutonium dissolved in the mercury in the mercury trap during the SRAT reaction cycle to be less than 6×10^{-6} grams of plutonium per gram of mercury.¹⁹ This concentration is too

low to accumulate enough plutonium in the mercury trap to cause a concern.

- (5) There is a concern relating to fouling of the SRAT vessel and subsequent clean-up procedure. However, there is no reference cleaning procedure and, therefore, a nuclear criticality safety analysis of the clean-up operation of the SRAT has not been performed. If the SRAT internals are fouled by the sludge solids and a clean-up procedure has to be performed to restore the SRAT to operational status, the clean-up procedure is viewed as an abnormal operation which is not covered under this assessment. Once this process is defined, its safety (in terms of criticality) will be evaluated.

Melter

The nuclear criticality concerns in the Melter have been discussed before.¹⁶ Additional issues were, however, asked to be considered.

A nuclear criticality evaluation²⁰ was performed on the melter using Batch 1 composition. It was concluded that the system remains subcritical for an infinite system under normal operations. There was no separation mechanism of plutonium and uranium in the melter. The melter system is safe due to the large amount of boron in the glass frit and the fissile materials not separating and accumulating.

Following are discussion of two additional issues related to the nuclear safety of the melter.

- (1) There has been a concern about plutonium accumulation in the melter which could be a potential source of a nuclear criticality incident during the melter's 2-year life.²¹ Experimental data indicates that the plutonium oxide is soluble in borosilicate glass at the ratio of 6×10^{-3} g PuO₂ per gram of frit.²² Using optical and Mossbauer spectra, Karraker²² inferred that from the valence state, Pu is a part of the borosilicate network. Plodinec and Wiley indicated that as much as 7% plutonium oxide is soluble in borosilicate glass.²³ The plutonium oxide to frit ratio during Batch 1 operation in S-area will be about 2×10^{-5} g PuO₂ per gram of frit.¹ The amount of plutonium in the melter is low compared to the amount of plutonium which is

known experimentally to be in solution with borosilicate glass. Under normal melter operation, no plutonium separation and, hence, no accumulation in the melter is possible.

- (2) In an early nuclear safety assessment¹⁶, a scenario was considered where a SME batch was added to the melter without the frit. It was determined that it was safe because the K_{∞} was very low, 0.063.²⁴ The concern was raised on what will happen when the fissile material is drained into the dump canister. Since K_{∞} is valid for any geometry, nuclear criticality in the dump canister or in the drain valve under this scenario is impossible.

In a similar fashion, Williamson¹⁷ also showed that the infinite multiplication factors for the SME feed with 1% water is 0.73 using Batch 1 sludge composition and assuming that the U-235 content is 20 weight percent of the total uranium. Nuclear criticality is, therefore, considered impossible if the SME feed is mistakenly added to the melter without glass frit.

The Process Vent and Off-Gas Systems

There have been situations, both on-site and off-site, indicating that solids accumulation in the vent systems can be a significant nuclear safety concern. However, it is not believed that this will be the case in the DWPF's process vent and off-gas system.

In the DWPF vent and off-gas systems, entrainment is the only mechanism for solid accumulation. Since there will be no preferential separation of fissile material from the bulk solids, nuclear criticality is not possible as shown in the DWPF sludge feed section. There will always be abundant amounts of Fe and Mn in the sludge to prevent nuclear criticality in the entrained solids.

Solid accumulation in the melter's off-gas system may depend more on the volatiles of the melter feed's components rather than by entrainment. However, boron, which is added in large quantities as borosilicate glass frit, is considerably more volatile than U and Pu and would accumulate in larger amount in the melter off-gas systems. The accumulation of fissiles in the melter's off-gas system in sufficient concentration to cause a concern is not credible.

Mercury Purification

Water and mercury distilled from the SRAT during boil-up will be collected continuously in the Mercury Water Wash Tank (MWTT). Condensate will be transferred to the SRAT and SMECT. Undistilled mercury and amalgamated metals which have accumulated in the SRAT sump will be transferred to the MWTT.

Mercury will be washed with water to remove entrained sludge, formic acid and other contaminants. Washed mercury is transferred to the Mercury Purification Cell and washed with nitric acid to remove water insoluble salts. A final scrub is provided by passing mercury countercurrent with nitric acid through packed columns and water scrub streams. After analyzing to confirm the radioactivity is below detectable limits, the washed mercury is vacuum distilled and stored before shipment to 200-H Area.

Since plutonium does not accumulate in the mercury trap of the SRAT vessel, there is no concern in the mercury purification system.

Recycle Collection Tank (RCT)

All radioactive waste solution generated in the S-Area DWPF will be neutralized and transferred to the waste farm through the Recycle Collection Tank. Contents of the RCT will be chemically adjusted to yield a solution of 1 M free hydroxide and 0.04 M nitrite¹⁶. The levels of corrosion inhibitors will ensure adequate corrosion protection for the waste receipt tank in the Interim Waste Storage Facility.

In the RCT, solids precipitate when the contents are neutralized. Uranium and plutonium are only slightly soluble in alkaline solution and will precipitate during the treatment.²⁵ Fe and Mn compounds are also known to be very insoluble in alkaline solution and will also precipitate.²⁶⁻²⁸ There is no reason to believe that solids will precipitate separately. The RCT is a stirred tank, and will mix the precipitated solids. The Fe and Mn to fissionable material weight ratios will be similar to the ratios in the sludge feed slurry, which has been established to be nuclear safe for Batch 1 sludge.

Decontamination Waste Treatment Tank

This concern is also related to the process vent and off-gas systems. HEME and HEPA filters are the active filter elements used in the process vent and off-gas systems. These spent filter elements will be processed in the Decontamination Waste Treatment Tank (DWTT). Since HEME and HEPA are both composed of fiberglass, they can be reduced to a slurry in a dilute sodium hydroxide solution. Subsequent treatment with nitric acid will dissolve all of the fiberglass solids.

There is a concern that solids accumulation in these spent filter elements could lead to separation and accumulation of fissile material in the DWTT after the filter element is dissolved. However, there is no mechanism to (1) accumulate significant fissile material in the filter element other than entrainment, and also no mechanism (2) which will preferentially separate the other solids from fissile material. Nuclear criticality is not possible because the Mn and Fe to fissile material weight ratios are still in excess of the calculated safe weight ratios. There will always be abundant amounts of Fe and Mn in the sludge to prevent nuclear criticality.

Conclusions

The DWPF will process the first batch, Batch 1 sludge¹, in a sludge-only mode. The precipitate feed will be a simulated nonradioactive stream. There will be no fissionable material in the precipitate feed stream, and, hence, nuclear criticality in the precipitate feed and process streams is impossible.

Batch 1 feed is composed of a dilute concentration of fissile material with an abundance of Fe, Mn, Al, U-238, Mg, Ni, Cr, and Hg. The Mn and Fe to fissile material weight ratios are in excess of the calculated safe weight ratios. Fe remains predominantly in the sludge solids throughout the DWPF processes. 50% of Mn will be dissolved in formic acid during Precipitate Hydrolysis Aqueous (PHA) addition. But there is still a sufficient amount of Mn remaining to maintain weight ratios well above the calculated safe weight ratios. The large margin of safety associated with the Fe and Mn to fissile material weight ratios will not be impacted during normal operation of DWPF processing sludge-only Batch 1 feed.

In process areas such as the Salt Processing Cell, the Chemical Processing Cell, and the Melter Cell, where there are significant chemical reactions taking place, Nuclear Criticality Safety Evaluations (NCSE) were performed for each processing cell. These analyses provide confirmation and verification of the safety basis established by this report. Analysis for the Salt Processing Cell was not completed pending further investigation of the chemistry of MST in boiling formic acid solution. Analysis of the Chemical Processing Cell and the Melter Cell confirmed that DWPF normal operations processing sludge-only Batch 1 sludge are subcritical.

Recommended Actions

Concentrations of Pu, U, Fe and Mn should be monitored in the S-Area DWPF process. In addition, isotopic analysis of Pu and U will be performed to confirm DWPF feed compositions. The sample results will not be used as a control since there are no controlling limits for DWPF Sludge Batch 1 operation. The sample results will be used to confirm that the Mn and Fe to fissile material weight ratios are still in excess of the calculated safe weight ratios.

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