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NUCLEAR AND CHEMICAL SAFETY ANALYSIS PUREX PLANT 1970 THORIUM CAMPAIGN

May 22, 1970

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NUCLEAR AND CHEMICAL SAFETY ANALYSIS
PUREX PLANT 1970 THORIUM CAMPAIGN

I. INTRODUCTION

The flowsheet for processing 400 tons of thoria irradiated to an average of 1,600 grams of uranium-233 per ton of thorium is discussed in Reference 1. Criticality prevention specifications for the processing operation are given in Reference 2. The purpose of this document is to discuss the flowsheet and the related processing equipment with respect to nuclear and chemical safety. The analyses presented are based on equipment utilization and revised piping as outlined in the design criteria (Reference 3). All criticality prevention considerations are based on the technical criteria given in Reference 4.

II. SUMMARY

Processing of thorium and uranium-233 in the Purex Plant can be accomplished within currently accepted levels of risk with respect to chemical and nuclear safety if minor instrumentation changes are made. These changes are defined by Table II. On the basis of the flowsheet shown in Reference 1, uranium-233 processing is limited to a rate of about 670 grams per hour by equipment capacities and criticality safety considerations. The major criticality prevention problems result from the potential accumulation of uranium-233 in a solvent phase in E-H4 (ICU concentrator), TK-J1 (IUC receiver), and TK-J21 (2AF pump tank). The same potential problems exist in TK-J5 (3AF pump tank) and TK-N1 (3BU receiver), but the probabilities of reaching a critical condition are not as great. In order to prevent the excessive accumulation of uranium-233 in any of these vessels by an extraction mechanism, it is necessary to maintain the uranium-233 and salting agent concentrations below the point at which a critical concentration of uranium-233 could be reached in a solvent phase.

III. NUCLEAR SAFETY

The bases for thorium-uranium-233 criticality prevention in an aqueous processing system are similar to those for uranium-plutonium. For example, just as there is an "always-safe" ratio of plutonium to uranium, there is an analogous "always-safe" ratio of uranium-233 to thorium. In Table I, some of the criticality safety limitations that have been the bases for uranium-plutonium systems at the Purex Plant are compared to the corresponding values for the thorium-uranium-233 system. These latter values provide one of the bases for control requirements and limitations described in this document.

The application of the control limitations to processing at the Purex Plant is based on (a) the thorium processing flowsheet that is defined in Reference 1, and (b) the equipment utilization and piping required for this flowsheet as defined by Reference 3. However, in many cases,

the criticality prevention limit as stated in the specifications for a certain vessel is less than the maximum always-safe ratio, concentration, or mass for that vessel. The reason for this is that operation of the vessel at limits greater than those stated would produce a violation of the specifications downstream in the process where the material has been concentrated or the vessel size or design requires a reduced concentration or mass. Thus, the required always-safe ratios or concentrations may be less than those shown in Table I.

As shown in the reference documentation, the general processing scheme and sequence for thorium-uranium-233 separation is similar in many ways to uranium-plutonium separation. The similarities are, perhaps, particularly apparent in Figure 1, "Thorium Process Flow Sketch (1970 Campaign)." This flow sketch is included as a valuable reference in the study of nuclear safety analyses that are presented below. The instrument alarms that have been recommended for the Purex Plant on behalf of good criticality control are shown in Table II.

In the development of the recommended processing controls and limitations, a basic "normal maximum" processing rate of 670 grams of uranium-233 per hour has been used with the flowsheet as defined (Reference 1) and in the equipment that will be available (Reference 3). This rate results in stream concentrations that are consistent with acceptable criticality safety. At the same time, the value is consistent with the Purex Plant equipment capacities. At the expected maximum instantaneous thorium processing rate of about 8 tons per day and the uranium-233 processing rate of 670 grams per hour, the equivalent ratio of uranium-233 to thorium in the HAF would be 2,000 grams per ton. With irradiated thoria targets from the reactors ranging from 950 to 2,280 grams/ton and averaging about 1,600 grams/ton, a recommended control value of 2,000 grams/ton for the HAF permits good capacity for uranium-233 rework and is consistent with the 670 grams/hour value in downstream equipment. Because some of the irradiated thoria targets will contain as much as 2,280 grams/ton thorium, a control value of 2,500 grams/ton has been set for the dissolver and headend operation. As is normal practice, the recommended process control values for always-safe ratios will be set lower than the allowable maximum values shown above.

In the paragraphs below, detailed analyses of criticality safety are presented for the equipment pieces of importance to the planned thorium campaign. The equipment of the Second Thorium Cycle is not included since this equipment handles virtually no uranium-233 and criticality analyses are not applicable. The manner of presentation of the analyses is as follows:

a. The primary mechanism for criticality safety, based on the chemical flowsheet, is described. In some cases, a suggested control limit is also shown in parenthesis. (However, these limits should not be construed to be specifications.) Specifications are presented in Reference 2.

b. Where applicable, and for cases in which the assessment of risk indicates the utilization of an available secondary control to be desirable, the secondary control method is also described, with the suggested control limit.

c. Recommendations for blanking process lines are presented in this document where unneeded or potentially hazardous connections exist. The types of blank to be used are listed in the criticality prevention specification (Reference 2) and the process control blanking schedule.

d. Potential errors that would violate criticality safety criteria are presented, and in-place preventatives that would preclude such an error are described. In many instances, conditions analogous to those that might be encountered and controlled during normal uranium-plutonium processing are apparent. Many of these cases are indicated.

The concentrations of uranium-233 in the aqueous and organic phases that are used in the discussion below are based on (a) the flowsheet presented in Reference 1, (b) Figure IV-18 ("Uranium Equilibrium Diagram, Arithmetic Coordinates - 30% TBP") of HW-31000, "Purex Technical Manual," and (c) Figure IV-16 ("Distribution of Uranium, Effect of TBP Concentration") of HW-31000, "Purex Technical Manual." The distribution ratio (E_a^o) of uranium-233 in 100 percent TBP, based on extrapolation of Figure IV-16, ranges from three to four-fold greater than in 30 percent TBP. For purposes of this study, a four-fold greater value was assumed. Laboratory studies indicate that the uranium E_a^o in 100 percent TBP is actually less than four times the E_a^o in 30 percent TBP.

The analyses below are presented in the order of functional processing sequence described by Reference 1. The nomenclature for processing areas, names, and maximum volumes for the vessels are shown in Table III. For each analysis, the line of reasoning leads to the general conclusion that the criticality risks for thorium-uranium-233 processing are consistent with those associated with present-day uranium-plutonium processing.

1. Coating Removal, Thoria Dissolution, and Acid Removal

A. Vessels: Dissolvers A3, B3, and C3; Acid Boil-Off Concentrator E-F11; Tanks D1, D2, D3, D4, E1, E3, E5; Centrifuges G-E2 and G-E4.

(1) Primary Control Mechanism

Always-safe ratio of 2,500 grams of uranium-233 per ton of thorium.

(2) Potential Errors and Preventatives

a. Uncontrolled addition of fissile material.

Prior to the introduction of irradiated thorium, plutonium will have been removed from these vessels by exhaustive flushing.

A possible error is the charging of irradiated normal uranium (at an always-safe ratio) to a dissolver during thorium processing. This possibility will be avoided by special procedures in place at the reactor basin to preclude the intermixing of uranium and thorium elements, and by special markings and loading patterns that will enable viewing from the crane to confirm that the buckets contain thorium. The Purex tunnel-gamma monitor will also detect irradiated uranium in the event of its inadvertent shipment. Sampling and chemical analysis of the dissolver feed solution could be also used to insure control. No criticality safety hazard would be created in these vessels by the error described, unless the plutonium was selectively accumulated by a mechanism described below.

b. Selective accumulation of fissile materials by the addition of tributyl phosphate or by precipitation.

The addition of solvent to these vessels requires complicated routing changes that will not be authorized.

No serious precipitation hazard exists because uranium-233 will not selectively precipitate from thorium under any foreseen conditions, the quantity of protactinium is small, and plutonium in quantity would have to be added to the system. Unlike uranium, plutonium and protactinium will precipitate (as "polymer") in systems containing little or no acid. Protactinium-233, the 27.4-day half-life precursor of uranium-233, will be present in the dissolved feed up to an average of about 0.15 percent of the total 233 isotope, equivalent to about 1 kg of uranium-233 for the entire thorium campaign. Plutonium will be excluded, as described under (a) above. Even so, based on the plutonium limit of 250 grams per square foot, about 12 kg of uranium-233 and Pu-239 can be tolerated as precipitate in any of the vessels specified above, except for Centrifuges G-E2 and G-E4. Greater than 4 kg of uranium-233 (or Pu-239) are required for a criticality condition in the centrifuges; ample additional safety factor results from the fact that each centrifuge will be exposed to only about 10 percent

of the fissile material that is scheduled for processing during this campaign. The hazard of uncontrolled precipitation by the addition of a precipitating reagent to any of the above vessels is essentially the same as for plutonium processing. Such additions are prevented by routing designs and by administrative controls. Criticality limitations based on precipitation are similar for uranium-233 and plutonium; if anything, the risk in a plutonium system may be slightly greater because of the possibility of higher concentrations of a polymeric form.

B. Vessels: Tanks D5, E6, F12, H1

(1) Primary Control Mechanism

The always-safe ratio of < 2,500 grams of uranium-233 per ton of thorium in TK-D5, TK-E6, and TK-F12, and < 2,000 grams of uranium-233 per ton of thorium in TK-H1.

(2) Secondary Control Mechanism

Safe concentration of < 6 grams of uranium-233 per liter in solution.

(3) Potential Errors and Preventatives

a. Uncontrolled addition of fissile material.

Routings exist in the Purex Plant for transferring plutonium to TK-D5, TK-E6, and TK-F12, from TK-F8, TK-F13, TK-L11, and the recycle hood in the Sample Gallery. In order to avoid transfer of stored in-canyon plutonium solution (e.g., from TK-F8 or TK-F13) during the planned thorium campaign, routings will be removed from service and blanks will be installed as necessary. Administrative procedures will be used to prevent transfer of plutonium and the uncontrolled transfer of uranium-233 by other routings. Essentially the same administrative procedures are used for controlling plutonium addition (for rework) during normal uranium-plutonium processing.

A control limit of 2,000 grams of uranium-233 per ton of thorium is established for the HAF process stream (from TK-E6 via TK-H1 to the HA Column) in order that control of the downstream E-H4 concentrator at < 0.95 grams uranium-233/liter can be maintained. Since the normal dissolver stream will be about 1,600 grams/ton, a margin of 400 grams/ton is provided for the recycle of uranium-233 from TK-L11 to TK-E6.

b. Selective accumulation of a fissile material by precipitation.

If plutonium were present under the acid-deficient conditions of TK-D5, TK-E6, TK-F12, and TK-H1, it could precipitate by polymerization. On the basis of a limit of 250 grams per square foot, about 18 kg of plutonium could be tolerated as a uniform precipitate without reaching a condition of criticality. However, as discussed above, plutonium will have been removed from this system by exhaustive flushing prior to the start of the thorium campaign, and the addition of plutonium from external sources will be prevented by proper blanking.

c. Selective accumulation of a fissile material in a solvent phase.

Uranium-233 solutions in TK-L11 and thorium solutions in TK-K6 can be recycled to TK-E6, and solutions in TK-E6 can be routed to TK-D5 and to TK-H1. Since both TK-L11 contents and TK-K6 contents are produced by solvent extraction, a potential exists for the presence of solvent phases in these vessels (as a result of column flooding) that would also be transferred to TK-E6. The solvent phases could have been processed through concentrator equipment used for product concentration, in which case, they would be degraded and concentrated with respect to TBP. Theoretically, in a severe case, red oil might be found. In the absence of thorium in TK-E6 or TK-H1, a solvent phase of this nature could theoretically concentrate the uranium-233 to as high as 425 grams per liter for solvent equivalent to 100 percent TBP. However, the uranium E_a^o would be markedly reduced by the co-extraction of thorium in the solvent phase, and the estimated uranium-233 concentration in the solvent phase would be limited to < 5 grams/liter.

The likelihood of transferring any appreciable solvent phase via the recycle system is very small. Instrumentation is in place for the detection of column flooding, and the presence of solvent phase in a downstream tank should be detected during sampling for process control. In the case of uranium-233 product, the final solvent-extraction product stream (3BU) is routed to TK-N1 prior to further processing. In TK-N1, any solvent phase would separate and be held. The low specific-gravity alarm would indicate a condition of excessive solvent volume.

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2. Co-Decontamination and Partitioning Cycle

A. Vessel: HA Column, T-H2

(1) Primary Control Mechanism

The always-safe ratio of < 2,500 grams uranium-233 per ton thorium. (This limit is set in order to control the downstream E-H4 concentrator at < 0.95 grams uranium-233/liter.

(2) Potential Errors and Preventatives

a. Exceeding the always-safe uranium-233/thorium ratio as a result of excessive thorium losses.

On the basis of no greater than 2,000 grams/ton (uranium-233/thorium) in the HAF (see 1 B (3) a), an HAW thorium loss of at least 20 percent would be required in order to reach the control limit concentration of 2,500 grams/ton in the HA Column, T-H2. Operating experience at the Purex Plant has demonstrated that instrumentation and procedural controls are adequate to prevent losses of this magnitude. However, even without the beneficial effect of thorium, the normal maximum uranium-233 concentration in the HA Column is approximately 200-fold below the minimum critical concentration.

b. Excessive recycle of uranium-233 via the IBSU (HAO) stream.

The always-safe ratio of 2,500 grams/ton would be exceeded in the HA Column (T-H2) if the uranium recycle via the IBSU stream were greater than 25 percent of the normal maximum throughput.

Recycle of uranium to this extent could result only in the event of loss of the salting strength provided by thorium nitrate and nitric acid in the 1BX Column T-J6 or in the event of an approximate 40 percent increase in the T-J6 aqueous-to-organic flow ratio. In the former case, a thorium loss of the required magnitude is prevented by instrumentation and procedural control (see a above), and nitric acid control is ensured by use of an alarm system on the acid flow control system. In the latter case, low and high flow alarms are provided on the 1BX-H_2O stream to prevent large errors in the column flow ratios. Without these controls and assuming total recycle of uranium-233 via the IBSU (HAO) stream, greater than twelve-days time would be required at the planned

[redacted]

processing rate for the uranium-233 concentration in the HA Column to reach the minimum critical value of about 11 grams/liter.

B. Vessel: TK-J3

(1) Primary Control Mechanism

The always-safe ratio of < 3,000 grams uranium-233 per ton thorium, or a safe concentration of < 0.12 grams uranium-233/liter in solution. (This limit is required to ensure a safe solution concentration of < 2.5 grams/liter in the 1BX Column, T-J6.)

(2) Potential Errors and Preventatives

Exceeding the always-safe ratio by excessive recycle of uranium-233 via the 2BW and 3BW streams.

The always-safe ratio of 3,000 grams/ton would be exceeded in TK-J3 if the uranium recycle via the 2BW and 3BW streams were greater than 50 percent of the normal maximum throughput. From the start of such a loss, about four hours would be required to exceed the limit. A loss of this magnitude would be expected only in the event of loss of the 2BX-2BU and 3BX-3BU flows. Low-flow alarms on the 2BU and 3BU streams guard against this possibility. During shut down or other transient operations, the 3,000 grams/ton limit can be exceeded due to loss of thorium in TK-J3.

However, exceeding the TK-J3 concentration control would require an extensive loss of process control. The control limit of 0.12 grams/liter ensures operation of the 1BX Column, T-J6, within the desired concentration limit of 2.5 grams/liter. This concentration would be exceeded in TK-J3 only if the uranium recycle via the 2BW and 3BW streams were greater than 65 percent of the normal maximum throughput. At a 0.12 gram/liter concentration, the TK-J3 uranium-233 inventory is a factor of three below the safe mass for uniform precipitation which is 7 kg. Even so, it is planned to install blanks on chemical addition lines to this vessel, whereby precipitating agents might otherwise be accidentally introduced.

C. Vessel: 1BX Column, T-J6

(1) Primary Control Mechanism

A safe concentration in solution of < 2.5 grams/liter uranium-233.

(2) Potential Errors and Preventatives

a. Exceeding the safe solution concentration by reflux of uranium in the T-J6 Column.

The normal maximum mass of uranium-233 in the T-J6 Column is about 420 grams. This estimate corresponds to a value of about 0.063 gram/liter in the IBU (solvent) stream and an average value of about 0.07 gram/liter in the column. The maximum possible reflux of uranium-233 in T-J6 is estimated at about 3,000 grams, and this could occur only in the event of a substantial decrease in the 1BX acidity or a large increase in the aqueous-to-organic flow ratio. With a 3,000-gram holdup, the maximum uranium-233 concentration would still be nearly ten-fold less than the minimum critical concentration. Further, both the 1BX-HNO_3 and 1BX-H_2O streams are provided with alarms to guard against high and low flows and consequent loss of flow ratio or acidity control. The controls to be applied to the 1BX Column to ensure safe concentration of < 2.5 grams/liter are:

(a) The HNO_3 concentration in the 1BX stream shall not be less than 0.12M.

(b) The 1BX Column, T-J6, aqueous-to-organic flow ratio shall not exceed 0.7.

(c) The maximum temperatures of the 1BX and 1BXF streams shall be 35°C.

b. Exceeding the safe solution concentration by uranium recycle.

An increase in the uranium concentration in the 1BX Column, T-J6, could occur in the event of a uranium "loss" to the IBXT stream and recycle via the IBSU, HAP, and IBXF streams, or in the event of recycle "losses" via the 2BW and/or 3BW streams.

Assume a control concentration of 5 grams/liter of uranium-233 (< 50 percent of the minimum critical solution concentration). The attainment of this value in the aqueous-continuous phase of the T-J6 Column would require a minimum corresponding concentration of 0.37 gram/liter in the organic phase, which is possible only in the absence of acid. In order to attain a IBU concentration of 0.37 grams uranium-233 per liter, the IBXF concentration must be about the same. Attainment of

[redacted]

this IBXF uranium concentration requires a time interval of at least one day, with 100 percent IBSU recycle, and at least two days of 100 percent recycle via the 2BW or 3BW streams. To attain the minimum critical solution concentration of about eleven grams per liter, a minimum time interval of at least twelve days is required.

D. Vessel: 1BS Column, T-J7

(1) Primary Control Mechanism

A safe concentration in solution of < 2.5 grams/liter uranium-233.

(2) Potential Errors and Preventatives

a. Exceeding the safe concentration in solution by excessive recycle of uranium-233 via the IBXT stream.

As discussed under 2 C (2) b, control of uranium-233 recycle via the IBXT and IBSU streams at a rate less than 25 percent, as required for criticality control of T-H2, will present no problems. In the presence of normal thorium concentrations in the IBXT, this level of uranium-233 concentration will be well below an always-safe ratio.

In the event of a large loss of thorium nitrate and nitric acid (salting strength) in the 1BX Column, T-J6, a loss of uranium-233 to the IBXT might be visualized that would be above the always-safe ratio. Even assuming total loss of uranium-233 to T-J7, however, the normal maximum concentration of uranium-233 in the IBXT would be only about 0.12 gram/liter, and the maximum column holdup (no 1BS flow) would be about 800 grams.

No problem of uranium reflux can be visualized because the required conditions for high salting strength localized at the bottom of T-J7 cannot be hypothesized.

E. Vessel: TK-J2

(1) Primary Control Mechanism

A safe mass of < 3 kg uranium-233 for possible uniform precipitation.

(2) Secondary Control Mechanism

Safe concentration of < 2.5 grams/liter uranium-233 in solution. (This limit ensures the desired concentration limit of < 2.5 grams/liter in the 1BX Column, T-J7.)

(3) Potential Errors and Preventatives

Exceeding the safe mass for uniform precipitation by excessive recycle of uranium-233 via the IBXT and IBSU streams.

The maximum allowable mass of uranium-233 in TK-J2, assuming uniform precipitation, is 3 kg. The corresponding TK-J2 uranium concentration would be 0.6 gram/liter, a value which represents a IBSU recycle loss of at least 190 percent. To attain this recycle, a uranium accumulation of at least 5 kg in T-H2, TK-J3, TK-J2, and T-J7 is required. This would require seven hours at a normal maximum processing rate and would effectively require complete partitioning failure in the 1BX Column (T-J6), with all the uranium-233 flowing via the IBXT stream and the IBSU stream to TK-J2.

Assuming this could happen, criticality control would be maintained by ensuring that precipitation could not occur. Chemical addition lines to TK-J2 will be blanked as necessary to avoid the addition of precipitating agents.

The concentration corresponding to the safe mass for uniform precipitation (0.66 gram/liter) is approximately four-fold less than the control value for safe solution concentration of 2.5 grams/liter. To attain 2.5 grams/liter in TK-J2, an impossible IBSU recycle rate, equivalent to seven times the normal maximum uranium-233 throughput, is required.

F. Vessel: 1C Column, T-H3

(1) Primary Control Mechanism

A safe concentration of < 6 grams/liter uranium-233 in solution.

(2) Potential Errors and Preventatives

Exceeding the safe concentration by decreasing the 1CX flow or increasing the 1BU uranium-233 concentration.

The maximum concentration of uranium-233 in the 1C Column, T-H3, will be less than 0.13 gram/liter when operating at

the normal maximum rate of 670 grams of uranium-233 per hour, and the total holdup in the column will be about 500 grams. To increase the concentration to the control value of 6 grams/liter (55 percent of the minimum critical concentration) would require a drastic decrease in the 1CX flow. For example, with the 1CX flow decreased to about 5 percent of normal, about one day would be required to reach 6 grams/liter uranium-233 in the 1CU stream. The 1CX low-flow alarm will guard against this possibility. Also, very high 1CW uranium losses would be indicative of the problem.

At the normal T-H3 aqueous-to-organic flow ratio, a 1BU uranium concentration of about 30 times normal (2.5 grams/liter) would be required for the concentration in T-H3 to reach 5 grams/liter. An extremely unlikely combination of errors would be required to reach this condition. For example, if the T-J6 Column were operating at the maximum normal rate of 670 grams of uranium-233 per hour, the following chain of circumstances might cause the required 1BU uranium-233 concentration:

(a) Loss of HNO_3 in the 1BX, and a subsequent reflux of uranium-233 in the T-J6 Column;

(b) Sudden increase in the 1BX acidity, simultaneously with an approximate 35 percent increase in the T-J6 aqueous-to-organic flow ratio.

With high and low-flow alarms on the 1BX-HNO_3 and 1BX-H_2O stream, such a combination of errors would be unlikely. Reaching a concentration in the 1BU that would cause an increase in T-H3 concentration to the minimum critical value of approximately 11 grams/liter is even more remote.

3. Second Uranium Cycle

A. Vessel : E-H4, TK-J1

(1) Primary Control Mechanism

A safe mass of <8.2 kg for possible uniform precipitation.

(2) Secondary Control Mechanism

A safe concentration of <0.95 gram uranium-233 per liter with an acidity of <0.36M HNO_3 in solution. (These conditions will ensure a safe solution concentration in a 100 percent TBP phase.)

(3) Potential Errors and Preventatives

a. Sudden release of uranium reflux from the Co-Decontamination and Partition Cycle as a result of loss of operational control.

At normal maximum processing rate of 670 grams of uranium-233 per hour, the normal maximum masses of uranium in the E-H4 concentrator and in TK-J1 are 5.8 and 3.5 kg, respectively, at the normal operating levels. If a substantial loss of control of the upstream 1BX Column operation were assumed, up to 3 kg of uranium-233 could be refluxed in that system (see 2 C (2) a). Thus, a sudden release of that reflux, by corrective action, could increase the E-H4 inventory to approximately 9 kg in about thirty minutes. The primary control (8.2 kg, maximum) would thus be violated. However, the solution concentration of uranium-233 would reach 0.90 grams per liter, compared to the secondary control of 0.95 gram/liter. The degree of process control that is required to avoid a violation as described is consistent with many of the requirements of normal uranium-plutonium processing.

b. Over-concentration of the 1CU stream in the E-H4 concentrator as a result of failure of the weight factor and specific gravity instrumentation.

The normal working (overflow) volume for E-H4 is about 2,600 gallons. The minimum conceivable volume is about 950 gallons, equal to the volume below the tube bundles. Assuming the holdup of the maximum normal mass of 5.8 kg of uranium-233 in E-H4, the simultaneous loss of 3 kg of uranium-233 reflux from the upstream solvent-extraction cycle to E-H4 over a thirty-minute period, coupled with the loss of E-H4 instrumentation, could cause violation of the secondary control (< 0.95 gram/liter) if the E-H4 volume were decreased to 2,450 gallons during the same thirty-minute period. As a precaution against over-concentration, specific gravity and dual weight factor instrumentation are provided on E-H4.

Assuming that no organic phase is present in E-H4, the minimum critical solution concentration of approximately 11 grams/liter could be attained in not less than 46 hours, assuming volume reduction to the minimum value of 950 gallons during that period. Within a period of four hours, however, the immediate downstream vessels, E-H4 receiver (TK-J1) and 2AF pump tank (TK-J21), would have been pumped empty.

c. Accumulation of uranium-233 in a solvent phase in E-H4 or TK-J1 as a result of flooding of the 1C Column (T-H3).

Under the normal conditions of relatively dilute uranium and nitric acid in E-H4 and TK-J1, any organic phase, up to 100 percent TBP equilibrated with uranium, will float. Thus, unless the E-H4 (top) overflow is stopped during a flood of the 1C Column, T-H3, a solvent phase will not accumulate in that vessel. The T-H3 Column is provided with instrumentation to indicate the presence of organic in the bottom of that column (a flooding condition) to prevent discharge of organic into the E-H4 concentrator.

Specific gravity and double weight factor instrumentation will indicate a cessation of E-H4 overflow. The uranium-233 and nitric acid concentrations required to cause an organic phase to sink in the concentrator bottoms of normal density would be essentially impossible to attain. For example, the 1BX acidity would have to be near that of concentrated nitric acid. As discussed in prior sections, instrumentation alarms are provided to maintain the correct 1BX acidity. The assurance that an organic phase will float in E-H4 is primarily dependent on acidity of the 1BX stream, which in turn controls the acidity (salting strength) of the E-H4 aqueous phase. As with E-H4, under flowsheet conditions, a solvent phase will float in the receiver tank, TK-J1. With the TK-J1 agitator operating, a large volume of solvent phase should not accumulate but would be pumped out of the tank along with the aqueous. If a solvent phase did accumulate, at the normal maximum flowsheet concentration of 0.59 gram/liter uranium-233 and 0.25M HNO_3 in the aqueous phase, a volume of approximately 400 gallons of 100 percent TBP could contain the vessel mass limit (primary control) of 8.2 kg of uranium-233. The organic phase concentration of 5.4 grams/liter would be safe (11 grams/liter is the minimum critical solution concentration). The secondary control value of 0.95 gram/liter uranium-233 in the aqueous phase corresponds to a value of 6.2 grams/liter in a 400-gallon organic phase.

d. Precipitation of uranium-233 in E-H4 or TK-J1.

Precipitation agents are excluded from both E-H4 and TK-J1 by blanking all unused chemical addition lines to these vessels. Thus, precipitation of uranium-233 cannot occur. An accumulation of solids in the E-H4 tube bundles and on the E-H4 shell has occurred under

the high-salt conditions of normal uranium-plutonium processing. In the dilute uranium-233 system, this accumulation should not occur. However, assuming a uranium-233 deposition, a depth of about 1/4 inch on the outside of a stainless steel tube bundle would be required for criticality. This would be equivalent to a mass of more than 450 kg of uranium-233. At the shutdown of normal uranium-plutonium processing, it is expected that the normal relatively small deposition of siliceous solids will be present in E-H4 and TK-J1. Since the uranium-carrying properties of these solids have not been defined and because of the difficulty to adequately flush, present plans call for replacement of the E-H4 concentrator with a spare prior to uranium-233 processing. Tank J1 flushing should provide adequate cleanup of that vessel.

B. Vessel: TK-J21

(1) Primary Control Mechanism

Safe concentration in solution. (An aqueous phase composition of < 0.95 gram/liter uranium and < 0.36M HNO_3 is required to ensure a safe solution concentration (< 6 grams/liter in the 2B Column (T-J23) and the 3AF feed tank (T-J5) and a safe solution concentration (< 20 grams/liter) in a 100 percent TBP phase in TK-J21.) This control mechanism (rather than a safe mass) is recommended for TK-J21 because the system for agitation of TK-J21 is considered inadequate to ensure dispersion and prevent accumulation of a solvent phase.

(2) Secondary Control Mechanism

A safe mass of < 3.5 kg for possible uniform precipitation.

(3) Potential Errors and Preventatives

a. Over-concentration of E-H4 solution, resulting in greater than 0.95 gram/liter in the aqueous phase.

E-H4 concentrator is provided with specific gravity and dual weight factor instrumentation to guard against over-concentration.

b. Recycle of 2BU via the normal neptunium recycle route to TK-J21, resulting in violation of the concentration control limit.

A routing exists that permits recycle of neptunium to TK-J21 during normal uranium-plutonium processing

at Purex. During thorium-uranium-233 processing, the 2BU would recycle to TK-J21 via this routing if the jet that routes 2BU to TK-J5 were shut off. However, if this were to occur, TK-J5 volume would be depleted before the concentration limit in TK-J21 would be exceeded. In the event of a fractional loss of uranium-233 via this route over the course of the campaign, the increase in concentration would be detected by sample analyses before the concentration limit was exceeded.

c. Excessive uranium-233 concentration accumulated in a solvent phase.

At the normal maximum concentrations of uranium-233 (0.59 grams/liter) and HNO_3 (0.25M) in the aqueous phase, the uranium concentration in a contacting organic phase (100 percent TBP) could reach about 2.4 grams/liter. Assuming that an appreciable volume of a separate organic phase could be accumulated in TK-J21, to exceed the safe concentration of 20 grams/liter in a 100 percent TBP phase, the aqueous phase uranium-233 concentration must be increased to 4.5 grams/liter (8 times normal maximum) or the acidity in TK-J21 must be increased approximately five-fold to 1.2M. Excessive acidity could result from accidental transfer of acid via the existing addition line to TK-J21. The addition line will be blanked.

d. Precipitation of greater than the minimum critical mass for uniform precipitation by addition of a precipitating agent.

Assuming a working volume in TK-J21 of about 250 gallons, it is theoretically possible, at the assumed composition of the aqueous phase, that a substantial volume of organic could result in the holdup of 7 kg uranium-233 which would exceed the minimum critical mass for uniform precipitation. The accumulation should be detected by analytical means or by indication of the T-L2 (3B Column) alpha monitor (i.e., the uranium-233 concentration in the 3BU would decrease significantly). If the accumulation were not detected and the uranium-233 were accidentally precipitated, criticality could result. To prevent such an occurrence, all unused chemical addition lines to TK-J21 will be blanked to prevent the addition of a precipitating agent.

C. Vessel: 2A Column, T-J22

(1) Primary Control Mechanism

A safe concentration of < 3.5 grams of uranium-233 per liter* in solution. (This limit is required to ensure a safe solution concentration of < 6 grams/liter in the 2B Column, T-J23 and 3AF tank, TK-J5.)

(2) Potential Errors and Preventatives

a. Excessive reflux of uranium-233 in the 2A Column, T-J22, caused by omission of 2AS salting agent, by excessive 2AF rate, and/or by low 2AX flow.

A reflux in the 2A Column, T-J22, may be caused by a reduction in the 2AS salting agent. With other conditions normal, complete omission of the salting agent from the 2AS stream would increase the uranium reflux in the T-J22 Column scrub section to about 10 grams/liter. To exceed the concentration of 20 grams per liter without nitric acid in the 2AS stream, the uranium feed rate of the T-J22 Column must be at least ten times normal. Alternatively, the 2AX would have to be at least ten-fold low. At this low 2AX flow, over half of the uranium would leave the T-J22 Column with the 2AW stream. With the flow alarms that will be installed on the 2AF, 2AX, and 2BU streams, the sequence or errors described is not considered reasonable.

The following limits will ensure a safe solution concentration in the 2A Column (T-J22):

(1) The HNO_3 concentration in the 2AS stream shall equal or be greater than 0.1M.

(2) The maximum uranium-233 concentration in the 2AF tank (TK-J21) shall be 0.95 grams/liter. See Section 3 B (1).

(3) The maximum 2AF-to-2AX flow ratio shall be 4.1.

b. Precipitation of uranium.

All unused chemical addition lines to the 2A Column, T-J22, are blanked to prevent uranium precipitation.

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*See 8 A, Purex Sumps.

D. Vessel: 2B Column, T-J23

(1) Primary Control Mechanism

A safe concentration of < 6 grams uranium-233 per liter in solution. (This limit is required to ensure a safe solution concentration of < 6 grams uranium-233/liter in the 3AF tank, TK-J5.)

(2) Potential Errors and Preventatives

a. Excessive uranium-233 concentration caused by an excessive T-J22 Column processing rate, reduction of the 2BU flow, and loss of acidity in the 2AU stream.

A concentration of 20 grams/liter in the 2B Column could be exceeded under hypothetical conditions of a uranium-233 processing rate ten-fold above normal, plus stopping of the 2BU flow, plus absence of acid in the 2AU stream. With the flow alarms that will be installed on the 2AF, 2AX, and 2BU streams, the conditions described are not considered reasonable. Limiting the minimum 2B Column aqueous-to-organic flow ratio to 0.65, along with the 2A Column limits established in Section 3 C (2) a, will ensure a safe solution concentration in the 2B Column (T-J23).

b. Precipitation of uranium.

All unused chemical addition lines to the 2B Column, T-J23, are blanked to prevent uranium precipitation.

4. Third Uranium Cycle

A. Vessel: TK-J5

(1) Primary Control Mechanism

A safe concentration of < 6 grams uranium-233/liter in solution. (This limit is required to ensure a safe solution concentration in the 3A Column, T-L1, and the 3B Column, T-12, and a safe solution concentration of < 20 grams uranium-233/liter in a 30 percent TBP phase in TK-J5.)

(2) Potential Errors and Preventatives

a. Exceeding the safe concentration as a result of an excessive input rate via the 2AF stream (and through the Second Uranium Cycle columns).

A 2AF uranium flow rate to the 2A Column, T-J22, of 2,150 grams per hour (320 percent of the maximum normal rate) would cause the TK-J5 concentration to reach 3.8 grams/liter. The 2AF stream is provided with a high-flow alarm to prevent an excessive 2AF flow.

b. Exceeding the safe concentration by release of uranium-233 reflux to TK-J5.

The maximum amounts of uranium-233 that can be refluxed in the 1BX Column (T-J6), the 2A Column (T-J22), and the 2B Column (T-J23) are 3,000, 200, and 1,000 grams, respectively. If a maximum T-J6 Column reflux were released while otherwise processing at a steady-state maximum production rate of 670 grams per hour, the uranium-233 concentration in TK-J5 would reach a maximum of 2.6 grams/liter.

If the maximum T-J23 Column reflux (1,000 grams) were suddenly released, a maximum concentration of 3.0 grams/liter could result in TK-J5 with TK-J5 at the normal operating volume. However, the accumulation of 1,000 grams in the T-J23 Column would have been preceded by a corresponding depletion in TK-J5 unless both the 2BU and 2AF flows were simultaneously stopped for a period of about two hours. The 2BU stream is provided with a low-flow alarm to guard against uranium reflux in the T-J23 Column.

c. Accumulation of uranium in a solvent phase.

Since there is no concentration step between the 2B Column, T-J23 and TK-J5, the maximum TBP concentration in any solvent phase entering TK-J5 would be approximately 30 percent, rather than 100 percent. The normal maximum concentration of uranium-233 in TK-J5 is 1.7 grams/liter. At the flowsheet composition of salting agent (0.07M HNO_3), the uranium concentration in the solvent phase would reach approximately 0.5 grams per liter. Assuming that an appreciable volume of a separate organic phase could be accumulated in TK-J5, to attain 20 grams/liter in a 30 percent TBP phase (< 50 percent of critical), the aqueous phase nitric acid concentration must be increased by a factor of

[redacted]

20 to 1.5M. Such an increase in acidity could be caused by the loss of the 2AS flow to the 2A Column, T-J22. However, about twelve hours with no flow would be required for the necessary acidity to be attained, and the off-standard condition would be detected by stream analyses during this time. Excessive acidity could also result from accidental transfer of acid via the existing addition line to TK-J5. The addition line will be blanked to prevent such an occurrence.

d. Accumulation of uranium-233 as a precipitate, resulting in an excessive mass in TK-J5.

The hazard of uranium-233 precipitation is no greater than the corresponding hazard of plutonium precipitation during normal uranium processing. The control method for uranium-233 will be the same as for plutonium, viz., blanking of unused chemical addition lines to TK-J5. The minimum critical mass of uranium-233 in TK-J5 is 25 kg. The accumulation of 25 kg uranium-233 is not considered reasonable with normal procedural controls.

B. Vessel: 3A Column, T-L1

(1) Primary Control Mechanism

A safe concentration of < 22 grams per liter in solution. (This limit is required to ensure a safe solution concentration of < 40 grams/liter in the 3B Column, (T-L2) and TK-N1.)

(2) Potential Errors and Preventatives

a. Excessive reflux of uranium-233 in the 3A Column, T-L1, caused by omission of 3AS salting agent, by excessive uranium-233 input (3AF) rate, and/or by low 3AX flow.

With other conditions normal for the maximum uranium-233 processing rate, omission of salting agent from the 3AS stream would increase the uranium reflux in the T-L1 Column scrub section to a concentration of 16 grams/liter. To attain 22 grams/liter without acid in the 3AS stream, the 3AF uranium processing rate would have to be 3.8 times normal. A 3AX flow rate 3.8-fold below normal would also theoretically raise the uranium-233 concentration in the T-L1 scrub section to 22 grams per liter, but at this low 3AX flow, over one-fourth of the uranium would leave the T-L1 Column with the 3AW stream. A high-flow alarm is provided on the 3AF stream to guard against an excessive 3AF flow,

and a low-flow alarm is provided on the 2AX stream to guard against low 3AX flow.

The following limits will be employed to ensure a safe solution concentration in the 3A Column, T-L1:

(a) The HNO_3 concentration in the 3AS stream shall be equal to or greater than 0.08M.

(b) The maximum uranium-233 concentration in the 3AF tank (TK-J5) shall be 6 grams/liter (Section 4 A (1)).

(c) The maximum 3AF-to-3AX flow ratio shall be 3.7.

b. Precipitation of uranium.

All unused chemical addition lines to the 3A Column, T-L1, are blanked to prevent the addition of a precipitating agent.

C. Vessel: 3B Column, T-L2

(1) Primary Control Mechanism

A safe concentration of < 40 grams/liter in solution for the SNA sump.

(2) Potential Errors and Preventatives

a. Excessive concentration caused by an excessive T-L1 Column processing rate and/or loss of 3BU flow.

A concentration of 40 grams uranium-233/liter in the T-L2 Column could be attained if the uranium-233 in the 3AU reached about 40 grams/liter (six times normal) as a result of excessive concentration in the 3A Column. This condition and preventatives are discussed under Section 4 B. Interruption of the 3BU (3BX) flow could also result in a 40 grams/liter concentration in the 3B Column. A low-flow alarm is provided for the 3BU stream to prevent this occurrence. Limiting the minimum 3B Column aqueous-to-organic flow ratio to 0.55 along with the limits of Section 4 B (2) a. will ensure safe solution concentration in the 3B Column, T-L2.

b. Precipitation of uranium.

All unused chemical addition lines to the 3B Column, T-L2, are blanked to prevent the addition of a precipitating agent.

D. Vessel: TK-N1

(1) Primary Control Mechanism

A safe concentration of < 40 grams/liter in solution.

(2) Potential Errors and Preventatives

a. Excessive uranium-233 concentration originating in the upstream T-L1 and/or T-L2 Columns.

The preventatives for this occurrence are discussed in Sections 4 B and 4 C above.

b. Accumulation of uranium-233 as a precipitate.

The probability and hazards of uranium-233 precipitation are no greater than for plutonium during normal uranium processing. The same precautions apply.

c. Excessive uranium-233 concentration accumulated in a solvent phase.

At the normal maximum concentrations of uranium-233 (7.6 grams/liter) and HNO_3 (0.024M) in the aqueous phase, the uranium concentration in a contacting organic phase (30 percent TBP) could reach about 2 grams/liter. Assuming that an appreciable volume of a separate organic phase could be accumulated in TK-N1, to attain 40 grams/liter in a 30 percent TBP phase, the aqueous phase uranium-233 concentration must be increased to 35 grams/liter (four times normal maximum) or the acidity in TK-N1 must be increased approximately 50-fold to 1.2M HNO_3. Such an increase in acidity could be caused by the loss of the 3AS flow to the 3A Column (T-L1). However, about one day with no flow would be required for the necessary acidity to be attained, and the off-standard condition would be detected by stream analyses. Excessive acidity could also result from accidental transfer of acid via the existing addition line to TK-N1; however, the addition line will be blanked.

E. Vessels: E-N6, TK-N7, TK-N20, T-N50, New TK-L9, and TK-L13

(1) Primary Control Mechanism

A safe concentration of < 450 grams uranium-233/liter in solution. (This limit is set on the basis of the SN sump requirement.)

(2) Potential Errors and Preventatives

a. Over-concentration.

Concentration of uranium-233 above the control limit of 450 grams/liter is possible; however, all of these vessels are geometrically safe for uranium-233 solution to 2,200 grams/liter. The E-N6 concentrator is equipped with specific gravity and weight factor instrumentation of the same type that has been successfully used in controlling the concentration of plutonium solutions during normal uranium processing. In addition, the E-N6 concentrator steam pressure is limited to a maximum of 29 psig (135°C) which limits uranium concentration to a maximum of 1,500 grams/liter (bp = 135°C).

F. Vessel: TK-L11

(1) Primary Control Mechanism

a. A concentration of less than 450 grams uranium-233/liter in solution.

b. The maximum volume in TK-L11 and the SLD sump shall be 7.2 gallons unless the combined mass of uranium-233 in TK-L11 and SLD sump is less than 3kg, then the maximum combined volumes may be 23.2 gallons.

c. A safe concentration for transfer to TK-E6 as indicated below. (This limit is set on the basis of the SE sump requirement.) The equivalent reactivity of rework solution transferred to TK-E6 via the existing jet (2.7:1 minimum dilution) will be controlled at less than 6 grams/liter by the following limits:

TK-L11 U-233 + Pu-239 Conc.	Required Motive Fluid
(1) $\leq$ 16 g/l	$HNO_3 \geq 0.2M$; cadmium use is optional.
(2) $>$16 to 200 g/l	$HNO_3 \geq 0.2M$ plus Cd $\geq 0.23M$
(3) $>$ 200 g/l	Must be diluted in TK-L11 to the range given in (2) above prior to transfer.

(2) Potential Errors and Preventatives

a. Concentrations of uranium-233 up to 450 grams/liter are permissible in the four-inch-diameter TK-L11 (24-gallon volume) which is safe for uranium-233

[redacted]

solutions to 2,200 grams/liter. However, uranium-233 solutions exceeding those concentrations shown in the table above could not be transferred to TK-E6 for rework. Sampling, chemical analysis, and administrative control will be used to ensure operation within the controls listed above.

b. Because of the potential buildup in sump SLD in case of a rupture of TK-L11, the combined total volume is limited to 7.2 gallons unless the combined total mass of uranium-233 is less than 3kg. Strict administrative control based on samples and weight factors will be used to ensure that these limits are not exceeded.

G. Vessels: T-L3, E-L4, TK-L6, TK-L10

(1) Primary Control Mechanism

A safe concentration of < 75 grams uranium-233 per liter in solution.

(2) Potential Errors and Preventatives

a. Concentration of uranium-233 solution in T-L3 or E-L4 and exceeding the safe concentration of 75 grams/liter.

The vessels listed above are not used during thorium-uranium-233 processing; however, 3BP solution can enter the T-L3 stripper and E-L4 concentrator by two mechanisms. The existing system for diverting 2BP to T-L3 during uranium-plutonium processing is a route for diverting 3BU uranium-233 solution into T-L3. Also, it has been observed during uranium-plutonium processing that solution from the 2BP sampler is entrained into T-L3 and E-L4 by the existing ventilation system. The uranium-233 concentration in the 3BU which could accumulate in T-L3 or E-L4 is controlled at less than 40 grams/liter as discussed in Section 4 C. This concentration is less than the safe concentration of 75 grams/liter. To prevent concentration of uranium-233 solutions in T-L3 or E-L4, the steam supply lines to T-L3 and E-L4 will be blanked and the ventilation jumper from the condenser vent header to the L Cell Package removed.

b. Transfer of solution to TK-L10 from TK-N7 and exceeding the safe concentration (75 grams/liter).

Routings exist in the Purex Plant for the transfer of solution from TK-N7 to TK-L10. TK-N7 can contain

uranium-233 concentrations up to 450 grams/liter. The existing TK-L10 is not used during uranium-233 processing; thus, the routes from TK-N7 to TK-L10 will be blanked.

5. Solvent Recovery

A. Vessels: G Cell and R Cell Vessels

(1) Primary Control Mechanism

A safe mass of < 500 grams uranium-233 per vessel.

(2) Secondary Control Mechanism

A safe concentration of < 4 grams uranium-233/liter in solution.

(3) Potential Errors and Preventatives

a. Excessive 1CW losses due to off-standard operation.

Excessive 1CW uranium-233 losses could be caused by a low 1CX-H_2O flow or a high 1CX-HNO_3 flow. Alarms are provided on the 1CX-H_2O and 1CX-HNO_3 streams to guard against these possibilities. In the event that a loss occurred in spite of the alarms, the wash solution in the first vessel of the G Cell system would remove the uranium-233 as a carbonate. In the event of a total loss of uranium-233 to the 1CW, the normal frequency of changing waste solutions would limit the maximum uranium concentration to 2.5 grams/liter.

Precipitation of uranium-233 as a carbonate will not be a controlling problem since the solubility of uranium in the dilute aqueous carbonate solution is greater than the minimum critical solution concentration of approximately 11 grams/liter.

b. Excessive 1CW losses due to solvent degradation.

Excessive 1CW uranium-233 losses could be caused by a high dibutyl phosphate concentration (from TBP degradation) in the 1CW stream. However, previous Purex run data and laboratory analyses indicate a uranium-233 loss by this mechanism is of no concern.

c. A high loss of uranium-233 in the 1BT stream would result in corresponding loss to the 2EW stream and to the R Cell vessels. However, unless the loss to

the 1BT stream exceeds 0.1 percent of the maximum uranium-233 processing rate, the uranium-233 in the 2EW will be less than one gram per hour. An excessive 1BT loss would be caused by a low 1BS flow. A low-flow alarm on the 1BS guards against this possibility.

6. Waste Concentration

A. Vessel: E-F6

(1) Primary Control Mechanism

A safe mass of < 4.5 kg uranium-233 for possible uniform precipitation.

(2) Secondary Control Mechanism

A safe concentration of < 2 grams uranium-233/liter in solution.

(3) Potential Errors and Preventatives

a. Excessive mass caused by high 2AW and/or 3AW uranium-233 losses.

At the maximum processing rate of 670 grams uranium-233 per hour, approximately seven hours of total 2AW or 3AW losses would be required to add 4.5 kg of uranium-233 to the E-F6 vessel.

Alarms on chemical addition streams, feed streams, and extractant streams are provided for both the 2A Column, T-J22, and the 3A Column, T-L1, to warn of conditions that might cause high 2AW or 3AW losses. In addition, the 2AW and 3AW losses will be monitored by routine chemical analysis. An alpha monitor is provided that will detect excessive 3AW uranium-233 losses.

With a continued total 2AW or 3AW loss, the E-F6 concentrator contents could contain a maximum of 1.8 grams uranium-233/liter, which is less than the secondary control concentration. (At 1.8 grams/liter, the mass in E-F6 would be 15 kg.)

B. Vessels: TK-F7, TK-F10, TK-F15, TK-F26

(1) Primary Control Mechanism

A safe mass of < 7 kg uranium-233 per vessel for possible uniform precipitation.

(2) Secondary Control Mechanism

Safe concentration in solution of < 2 grams uranium-233 per liter.

(3) Potential Errors and Preventatives

a. Excessive mass caused by high 2AW and/or 3AW uranium-233 losses.

At the maximum processing rate of 670 grams uranium-233 per hour, greater than ten hours of total 2AW or 3AW losses would be required to add 7 kg of uranium-233 to the vessels of the waste concentration system.

Alarms on chemical addition streams, feed streams, and extractant streams are provided for both the 2A Column, T-J22, and the 3A Column, T-L1, to warn of conditions that might cause high 2AW or 3AW losses. In addition, the 2AW and 3AW losses will be monitored by routine chemical analysis.

b. Excessive mass caused by organic accumulation in TK-F7 or TK-F10.

The aqueous waste tanks, TK-F10 and TK-F7, upstream of the F6 concentrator have the potential for organic accumulation. The organic would come from column effluent, either entrained under normal conditions or as a sudden burst from column instability. TK-F10 receives the aqueous waste streams from the Second and Third Uranium Cycles and the Second Thorium Cycle, 2AW, 3AW, and 2DW, respectively. TK-F7 subsequently receives this material as well as HAW from the First Decontamination Column.

TK-F10 has an agitator, which will routinely run, thus precluding an obvious organic accumulation. TK-F7 has no agitator and is intended to be an organic accumulator with sensing elements to warn of gross organic accumulation.

The worst conditions possible have been postulated for each tank to ascertain the uranium-233 concentration and mass which might accumulate in the respective tanks.

TK-F10

This tank receives 2AW, 3AW, 2DW, and vent jet condensate. The acidity is the primary salting agent and is routinely

less than 1.5M HNO_3. If organic does accumulate in TK-F10 for some reason such as agitator failure, the maximum concentration of uranium-233 in a 30 percent TBP phase will be approximately 2 grams per liter assuming a 100 percent loss in both 2AW and 3AW. At the maximum processing rate of 670 grams uranium-233 per hour and 3AF at flowsheet concentration, 8 hours would be required to add 7000 grams to TK-F10. Seven hundred gallons of 30 percent TBP and 2800 gallons of aqueous phase would be required to hold 7000 grams in TK-F10.

TK-F7

In TK-F7, 2.5 grams per liter is the maximum instantaneous uranium-233 concentration possible in a 30 percent TBP phase assuming a 100 percent loss in HAW, 2AW, and 3AW, or 1.7 grams per liter assuming only the 2AW and 3AW losses are 100 percent. The latter value will require 1,200 gallons of 30 percent TBP and 1,000 gallons of aqueous phase to accumulate 7,000 grams of uranium-233. The gross loss of 7,000 grams via 2AW and 3AW would be noted by samples in the uranium cycles. A gradual accumulation in a TK-F7 organic layer would require corresponding losses to the aqueous stream and would be noted in the high loss values in 1WW. The organic volume similarly would be noted if it suddenly went to TK-F7, and gradual buildup will be checked by periodically dropping the liquid level in TK-F7 through the 30-35-inch organic detection level.

If gross organic is observed in TK-F7 and uranium levels in the waste become high, the system could be then shut down and the organic phase and accumulated uranium-233 removed. These transfers could be made on a batch basis to ensure safe mass limits in the neutralized waste system (TK-F16, TK-F18).

C. Vessels: TK-F16, TK-F18

(1) Primary Control Mechanism

A safe mass of < 500 grams of uranium-233 per vessel.

(2) Potential Errors and Preventatives

These tanks are used for neutralization of process waste solutions before routing to underground storage. Accumulative analyses of the waste streams routed to these tanks and tank batch analyses will ensure that the 500-gram batch limit is not exceeded.

7. Acid Recovery

A. Vessels: TK-F3, T-F5, and U Cell Vessels

(1) Primary Control Mechanism

A safe mass of < 500 grams uranium-233 per vessel.

a. Addition of fissile materials.

Routing changes and/or a series of unrealistic processing errors are required to add any significant quantity of fissile material to these vessels. The same potential for exceeding this critical mass control exists during plutonium processing.

8. Purex Sumps

A. Sumps: SA, SB, SC, SD, SFA, SFB, SG, SH2, SJ, SJ2, SK, SR

(1) Primary Control Mechanism

A safe concentration of < 6 grams per liter of combined plutonium and uranium-233 in solution.

(2) Potential Errors and Preventatives

a. Process leaks with concentrations greater than 6 grams per liter of combined plutonium and uranium-233.

No normal process streams at an unsafe concentration can leak into these sumps, unless a leak occurs in the line from SLA to TK-F18 or in the line from TK-L11 to TK-E6. In the case of the L-11-to-E6 line, a leak in the all-welded pipe-trench line would be the only route to the sumps other than to the poisoned SE sump (See b below). In the case of the SLA-to-F18 line, special controls are required to overcome potential problems; viz., solutions containing greater than 6 grams/liter uranium-233 should not be transferred via this routing without special precautions and procedures.

Under abnormal processing conditions in the 2A Column, T-J22, and 2B Column, T-J23, a leak from this system, at greater than 6 grams/liter uranium-233, could conceivably occur which would flow to Sump SJ or SJ2. The normal maximum uranium concentration in this column system is about 5 grams/liter. If salting agent were completely omitted from the 2AS, a concentration of 10 grams/liter could be reached (compared to the minimum critical concentration of 11 grams/liter). For a solution of this concentration to reach Sumps SJ or SJ2, a leak in the system from the upper half of T-J22 through the lower half of T-J23 would be required.

B. Sump: SE

(1) Primary Control Mechanism

A safe concentration which is equivalent to the reactivity of 6 grams per liter of combined plutonium and uranium-233 in solution.

(2) Potential Errors and Preventatives

a. Leak in the process line from TK-L11 to TK-E6.

Potentially, solutions with uranium-233 concentrations up to 350 grams per liter could be transferred into TK-L11 for routing into TK-E6. However, after dilution by the TK-L11 jet transfer system, the maximum concentration in the transfer line would be 130 grams/liter. Thus, a potential exists for leaking 130 grams/liter uranium-233 into the SE sump via the wall nozzle in E Cell. This potential error will be prevented by sampling TK-L11 contents, diluting as necessary, and transferring the TK-L11 rework solution to TK-E6 with a cadmium nitrate and/or nitric acid solution. The equivalent reactivity of rework solution transferred to TK-E6 via the existing jet (2.7:1 minimum dilution) will be controlled at less than 6 grams/liter by the following limits:

TK-L11 U-233 + Pu Conc.	Required Motive Fluid
(1) $\leq$ 16 g/l	$HNO_3 > 0.2M$; cadmium use is optional.
(2) $>$ 16 to 200 g/l	$HNO_3 > 0.2M$ plus Cd $> 0.23M$
(3) > 200 g/l	Must be diluted in TK-L11 to the range given in (2) above prior to transfer.

C. Sump: SLA

(1) Primary Control Mechanism

a. A safe mass of < 50 kg combined uranium-233 and Pu-239.

b. A safe concentration of < 450 grams/liter combined uranium-233 and Pu-239 in solution.

c. Safe slab (< 1-inch depth above the 8-inch-deep sump unless analyses of two successive floor flushes indicate the combined uranium-233 and Pu-239 concentration to be less than 6 grams/liter and no uranium-233 or Pu-239 is added subsequently).

d. The steam supply to the SLA sump to TK-F18 jet shall be blanked unless the combined uranium-233 and Pu-239 concentration is less than 6 grams/liter.

(2) Potential Errors and Preventatives

a. Exceeding safe slab thickness.

Overfilling the SLA sump and thereby exceeding the safe slab thickness should be prevented by weight-factor instrumentation that is set to alarm at a 1/2-inch slab thickness. To increase the depth to one inch, 200 gallons of solution would be required.

D. Sump: SLB

(1) Primary Control Mechanism

A safe slab of < 1.7-inch-deep and with a concentration of 450 grams uranium-233 per liter in solution.

(2) Potential Errors and Preventatives

a. Failure of TK-L13 and/or exceeding the sump liquid-level limit.

Failure of TK-L13 would result in a maximum of 3 liters of uranium-233 solution to the SLB sump and, assuming the drain to SLA is plugged, would increase the level to 1.1 inches. Periodic inspections will be used to assure that the drain line from SLB sump to the SLA sump is maintained in a free-flowing condition and that uranium solutions do not accumulate.

E. Sump: SLC

(1) Primary Control Mechanism

A safe mass in solution of < 1.4 kg uranium-233 and Pu-239.

(2) Potential Errors and Preventatives

a. Exceeding the safe mass in the SLC sump.

The only foreseeable single error which could result in a gross quantity of uranium-233 in the SLC sump is [redacted]

the failure of a product bottle. The mass limit would not be exceeded in the event of failure of a single bottle, and the failure of two or more bottles is not considered reasonable.

F. Sump: SLD

(1) Primary Control Mechanism

A safe volume of less than 7.2 gallons in both TK-L11 and SLD sump, or a safe mass of less than 3Kg in which case the volume may be 23.2 gallons.

(2) Potential Errors and Preventatives

a. Exceeding the Safe Volume in the SLD Sump

In order to exceed the safe volume in the SLD sump, failure of the TK-L11 would be required with greater than 7.2 gallons of uranium-233 product solution in TK-L11 and the SLD sump. A weight factor alarm shall be in operation on TK-L11 during product loadout transfers.

b. Exceeding the Safe Mass Limit in the SLD Sump

In order to exceed the mass limitation on the SLD sump which applies when from 7.2 to 23.2 gallons are contained in TK-L11 and the SLD sump, greater than 3kg of uranium-233 must leak from a TK-L11 tank failure. When from 7.2 to 23.2 gallons of solution are contained in TK-L11 and the SLD sump, administrative procedures must be used to control the combined inventory below 3.0 kg of uranium-233.

G. Sumps: SLE, SLF

(1) Primary Control Mechanism

Maintaining the drain lines to the SLA sump in a free-flowing condition.

(2) Potential Errors and Preventatives

a. Undetected accumulation of uranium solutions by failure of process equipment, TK-L10, or by a leak in the transfer system from N Cell to TK-L11.

The SLE and SLF sumps drain to the SLA sump; thus, an accumulation could only result from an undetected

leak and an undetected plugged drain. Drains are protected by screens, and periodic inspections will be used to assure that the drain lines to the SLA sump are maintained in a free-flowing condition and that uranium solutions do not accumulate. In addition, TK-L10 will not be used for uranium-233 (See 4 G (2) b).

H. Sump: SN

(1) Primary Control Mechanism

A safe slab of solution less than 1.0 inches thick and with a concentration of < 450 grams uranium-233/liter.

(2) Potential Errors and Preventatives

a. Failure of processing equipment and/or exceeding the sump liquid-level limit.

The maximum safe depth in the SN sump is 1.7 inches. To ensure that this level is not exceeded, the normal liquid level in the SN sump is limited to a maximum depth of 1.0 inches. At the alarm point, an additional 22.7 gallons of solution could be added without exceeding the safe 1.7-inch depth. Failure of either E-N6 or TK-N6 could result in the loss of the contents of both vessels to the sump by virtue of their interconnection. If this "worst condition" occurred, the safe 1.7-inch depth (at 450 grams/liter) would not be exceeded. The Thorium Ion Exchange Column, T-N50, and the uranium-233 loadout storage tank, TK-N52, would also drain to the SN sump in the event of failure. Their volumes are small and could be readily contained within the limitations described above. Also, assuming a maximum allowable uranium-233 concentration of 40 grams/liter in TK-N1 at a maximum operating volume (approximately 60 gallons), the failure of this vessel and overflowing the SNA sump to the SN sump would not result in an unsafe configuration.

I. Sump: SNA

(1) Primary Control Mechanism

A safe slab of solution less than 0.9 inches thick with a concentration of < 40 grams uranium-233 per liter with the exception noted below:

Exception: Solution containing less than 450 grams uranium-233 per liter may be drained from TK-N20 into the SNA sump for immediate transfer to TK-L11 provided TK-N1 is either empty

of solution or known with reasonable certainty* to contain less than 500 grams of combined uranium-233 or plutonium.

(2) Potential Errors and Preventatives

a. Failure of the N1 tank or draining the N20 tank to the SNA sump and/or exceeding the safe slab limit.

Failure of the N1 tank would result in a maximum of 60 gallons of solution drained to the SNA sump and overflowing the SNA sump to the SN sump. The concentration in the N1 tank is limited to 40 grams uranium-233/liter as discussed in Section 4. With the level of the SNA sump at 0.9 inches followed by failure of the N1 tank, 20.8 gallons of solution would overflow the SNA sump to the SN sump. The resulting three-inch depth of 40 grams uranium-233/liter solution in the SNA sump and the less than 1.7-inch depth of solution (less than 450 grams uranium-233/liter) in the SN sump are both safe.

Draining of the N20 tank to the SNA sump would result in the addition of a maximum volume of four gallons at a maximum concentration of 450 grams uranium-233/liter to the SNA sump. If the N20 tank were drained to the SNA sump at a specification limit of 0.9 inches, the sump level would increase to 1.11 inches which is less than the safe value of 1.7 inches at 450 grams uranium-233/liter.

IV. CHEMICAL SAFETY

The processing of thorium and uranium-233 introduces two chemicals new to the Purex Plant. These chemicals are potassium fluoride and phosphoric acid. Since sodium fluoride is used during uranium-plutonium processing and phosphoric acid exists in the uranium-plutonium process from tributyl phosphate degradation, no new or unusual handling or processing problems will result from the use of these chemicals per se.

The thorium feed preparation operation introduces an acid boil-off of the thorium dissolver solution to the Purex Plant. This operation was performed in the 1966 thorium campaign without incident. Routing of acid boil-off waste solution directly to acid recovery is expected to increase the radioactivity of Purex recovered acid less than two-fold above the normal level experienced during uranium-plutonium processing. Although equipment arrangements, process routings, and the processing flowsheets differ from those used for uranium processing, no new or unusual hazards are introduced by any of these changes except the

*By analysis of at least two successive dilute (0.75M) nitric acid flush solutions.

potential hazards introduced by unfamiliarity. These changes should not pose any serious hazards since the Purex Plant personnel have demonstrated on several occasions their ability to handle new processes and tests of comparable complexity.

A review of the flowsheet in relation to the equipment used reveals only one deviation from current chemical safety practices. This deviation involves the use of E-N6 as a uranium concentrator, and the controls normally applied to uranium concentrators for the prevention of "red oil" reactions. The E-N6 concentrator usually operates on 34 psig steam and is not normally instrumentated for steam cut-off at low weight factor or high temperature. During the thorium run, the E-N6 concentrator will be limited to maximum steam pressure of 29 psig as are other uranium concentrators. In addition, the E-N6 concentrator will be provided with low weight factor and high specific gravity alarms.

V. REFERENCES

(1) ARH-1287 (secret), August 11, 1969, A. L. Boldt and G. F. Smith, "Purex Plant Chemical Flowsheet for the 1970 Thorium Campaign"

(2) ARH-1514 (unclassified), June 1, 1970, W. E. Matheison and G. C. Oberg, "Criticality Prevention Specifications - Thorium-Uranium-233 Processing in the Purex Plant"

(3) ARH-954 REV1 (unclassified), May 21, 1970, M. N. Raile and M. M. Beary, "Process Design - Improved Purex Thorium Processing"

(4) ARH-468 (unclassified), April 2, 1968, R. E. Tomlinson, "Technical Criteria for Prevention of Criticality - Chemical Processing Division"

Approved By: R E Van der Cook
for G. L. Ritter, Manager
Separations Process Engineering

Revised 7/13/70

[redacted]

[redacted]

TABLE I

CRITICALITY CONTROL LIMITATIONS
FOR Pu^{239} AND U^{233}

Control Limitations	Pu^{239}	U^{233}
Minimum Critical Mass, grams	520	590
Always-Safe Ratio, g/T	3050(1)	5000(2)
Minimum Critical Solution Concentration, g/l	7.8	11
"Geometrically Favorable" Cylinder-Vessel Diameter at 500 g/l(3), in.	7.1	5.1
"Geometrically Favorable" Slab - Thickness at 500 g/l(4), in.	3	2.0
Minimum Critical Mass for Precipitation, g/sq. ft.(5)	250	330

(1) Grams plutonium per ton for irradiated natural uranium. Value shown is in addition to the U^{235} content.

(2) Grams U^{233} per ton thorium.

(3) Pu^{239} (U^{233}) at 500 g/l in water, with 1/8 in. steel container walls surrounded by air.

(4) Pu^{239} (U^{233}) at 500 g/l in water, with concrete on one side.

(5) To avoid criticality in event of precipitation.

[redacted]

TABLE II

CRITICALITY PREVENTION ALARM SYSTEMS

Streams or Equipment Piece	Type of Alarm
1BX-HNO_3	Hi and Lo Flow
1BX-H_2O	Hi and Lo Flow
1CX-HNO_3	Hi and Lo Flow
1CX-H_2O	Lo Flow
1BS	Lo Flow
H_3 Column	Flood Detector
E-H4 Concentrator	Hi SpG
E-H4 Concentrator	Lo Wt. Fac. (Dual)
2AF	Hi Flow
2AF-HNO_3	Hi and Low Flow
2AX	Lo Flow
2BU	Lo Flow
3AF	Hi Flow
3AF-HNO_3	Hi and Lo Flow
3AX	Lo Flow
3BU	Lo Flow
TK-N1	Lo SpG
E-N6 Concentrator	Hi SpG
E-N6 Concentrator	Lo Wt. Fac.
E-N6 Concentrator	Hi Steam Pressure
TK-L11	Hi Wt. Fac.

TABLE III

PUREX PLANT VESSEL SCHEDULE
THORIUM - U^{233} PROCESSING

Vessel	Function	Nominal Volume Gallons	Size
TK-A3,B3,C3	Dissolver	4,000	9'3" OD x 4'11" ID x 16'
T-A3,B3,C3	NH_3 Scrub Waste	2,300	8'9" x 1'10" x 10'
TK-D1	Acid Boiloff Feed	5,000	10'0" x 9'3"
TK-D2	Coating Waste	5,000	10'0" x 9'3"
TK-D3	Acid Boiloff Feed	7,700	10'6" x 12'8" x 9'2"
TK-D4	Acid Boiloff Feed	7,700	10'6" x 12'8" x 9'2"
TK-D5	Stock TNT	5,000	10'0" x 9'3"
TK-E1	Centrifuge Product	1,700	7'0" x 6'9"
G-E2	Coating Waste Centrifuge	90	48"
TK-E3	Centrifuge Feed	5,000	10'0" x 9'3"
G-E4	Coating Waste Centrifuge	90	48"
TK-E5	Centrifuge Waste	5,000	10'0" x 9'3"
TK-E6	HAF Makeup	5,000	10'0" x 9'3"
TK-F3	AAA	5,000	10'0" x 9'3"
T-F5	Acid Absorber	300	10' OD x 9'3" - 3 1/2' OD x 17 1/2'
E-F6	1WW Concentrator	2,500	Two 4'5" barrels x 12' and One 2'6" barrel x 12'
TK-F7	1WF	3,800	6'9" x 10'6" x 9'2"
TK-F10	2WF	5,000	10'0" x 9'3"
E-F11	Acid Boiloff	2,500	Two 4'5" barrels x 12' and One 2'6" barrel x 12'
TK-F12	Stock TNT	5,000	10'0" x 9'3"
TK-F15	Denitration	5,000	10'0" x 9'3"
TK-F16	Denitration & Neutralization	5,000	10'0" x 9'3"
TK-F18	Utility Waste	5,000	10'0" x 9'3"
TK-F26	1WW Receiver	3,600	6'9" x 10'6" x 9'2"
TK-G1	10F	5,000	10'0" x 9'3"
T-G2	10 Column	1,100	34" Dia. x 32'
TK-G2	10S	1,900	8'0" x 7'9"
TK-G5	100	15,000	10'6" x 16' x 14'
TK-G6	10D Decanter	450	4' x 5'
TK-G7	Turbomixer	15,000	10'6" x 16' x 14'
TK-G8	10W	5,000	10'0" x 9'3"

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TABLE III - CONTD

PUREX PLANT VESSEL SCHEDULE
THORIUM - U^{233} PROCESSING

Vessel	Function	Nominal Volume Gallons	Size
TK-H1	HAF	5,000	10'0" x 9'3"
T-H2	HA Column	1,850	26" Dia. x 40'
T-H3	1C Column	1,770	34" Dia. x 26'
E-H4	1CU Concentrator	2,500	Two 4'5" barrels x 12' and One 2'6" barrel x 12'
TK-J1	1UC	5,000	10'0" x 9'3"
TK-J2	HAO	1,340	4'2" x 14'0"
TK-J3	1BXF	5,000	10'0" x 9'3"
TK-J5	3AF	370	8'6" OD x 8'0" ID x 8'11"
T-J6	1BX Column	1,600	32" Dia. x 33'
T-J7	1BS Column	1,770	34" Dia. x 26'
E-J8	1BT Concentrator	3,700	Two 4'7" barrels x 14' and One 2'6" barrel x 14'
TK-J21	2AF	320	4'5" OD x 3'11" ID x 14'8"
T-J22	2A Column	120	7" Dia. x 38'
T-J23	2B Column	90	7" Dia. x 24'
TK-K1	2DF	5,000	10'0" x 9'3"
T-K2	2D Column	1,370	24" Dia. x 16' - 32" Dia. x 16'
T-K3	2E Column	1,770	34" Dia. x 26'
E-K4	2EU Concentrator	3,700	Two 4'7" barrels x 14' and One 2'6" barrel x 14'
TK-K5	2UC Receiver	5,000	10'0" x 9'3"
TK-K6	TNT Product	5,000	10'0" x 9'3"
T-L1	3A Column	130	7" Dia. x 40'
T-L2	3B Column	90	7" Dia. x 30'
T-L3	----	12	Two 6" Dia. barrels x 7'
T-L4	----	12	Two 6" Dia. barrels x 7'
TK-L6	----	14	Two 6" Dia. barrels x 13'
TK-L9	U^{233} Product Sampler	11	Three barrels 5" Dia. x 38"
TK-L10	----	14	6" Dia. x 10'
TK-L11	U^{233} Recycle	30	Three 4" Dia. barrels x 12'
TK-L13	U^{233} Loadout	0.8	3" Dia. x 21"

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TABLE III - CONTD

PUREX PLANT VESSEL SCHEDULE
THORIUM - U^{233} PROCESSING

Vessel	Function	Nominal Volume Gallons	Size
TK-N1	3BU Receiver	64	2-5/8" x 8' x 5'
E-N6	3BU Concentrator	10	Two barrels 4.2" Dia. x 7'8"
TK-N7	3UC Receiver	10	Two barrels 4.3" Dia. x 5'3"
TK-R1	20F	5,000	10' x 9'3"
T-R2	20 Column	1,100	34" Dia. x 32'
TK-R2	20S	1,900	8' x 7'9"
TK-R5	Utility	9,000	10' x 14'
TK-R6	Utility Decanter	430	4' x 5'10"
TK-R7	200	9,000	10' x 14'
TK-R8	20W	5,000	10' x 9'3"
TK-U1	Recovered Acid	14,000	10'6" x 16' x 14'
TK-U2	Recovered Acid	14,000	10'6" x 16' x 14'
TK-U5	Fractionator Feed	9,000	10' x 14'
T-U6	Fractionator	1,750	8' x 32'
SA	A Cell Sump	45	24" x 24" x 18"
SB	B Cell Sump	45	24" x 24" x 18"
SC	C Cell Sump	45	24" x 24" x 18"
SD	D Cell Sump	45	24" x 24" x 18"
SE	E Cell Sump	30	24" x 24" x 18" (Filled with 1" Boron Raschig Rings)
SFA	F Cell Sump	45	24" x 24" x 18"
SFB	F Cell Sump	45	24" x 24" x 18"
SG	G Cell Sump	45	24" x 24" x 18"
SH	T-H2 Sump	2,600	9'0" x 6'9" x 4'11"
SJ	J Cell Sump	60	30" x 24" x 18"
SJ-2	J Cell Package Sump	2,700	9'9" x 8'2" x 5'
SK	K Cell Sump	60	30" x 24" x 18"
SLA	L Cell Sump	76	1 1/2" x 8" x 59'
SLB	TK-L13 Sump	0	2'2" x 2' x 2"
SLD	TK-L11 Sump	4.5	8'2" x 1'9" x 7"
SLE	TK-L9 Sump	0	21" x 19' (Slope 2 1/4" in 19')
SLF	TK-L10 Sump	0	21" x 19' (Slope 2 1/4" in 19')

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TABLE III - CONTD

PUREX PLANT VESSEL SCHEDULE
THORIUM - U^{233} PROCESSING

Vessel	Function	Nominal Volume Gallons	Size
SN	N Cell Sump	55	4' x 13' x 1.7"
SNA	TK-N1 Sump	56	3' x 10' x 3"
TK-N20	N Cell Vent Drain Tank	4	4" Dia. x 6"
T-N50	Throium Absorption Column	3.5	5" x 7'8"
TK-N52	----------	20 Liters	4" Dia. x 7'

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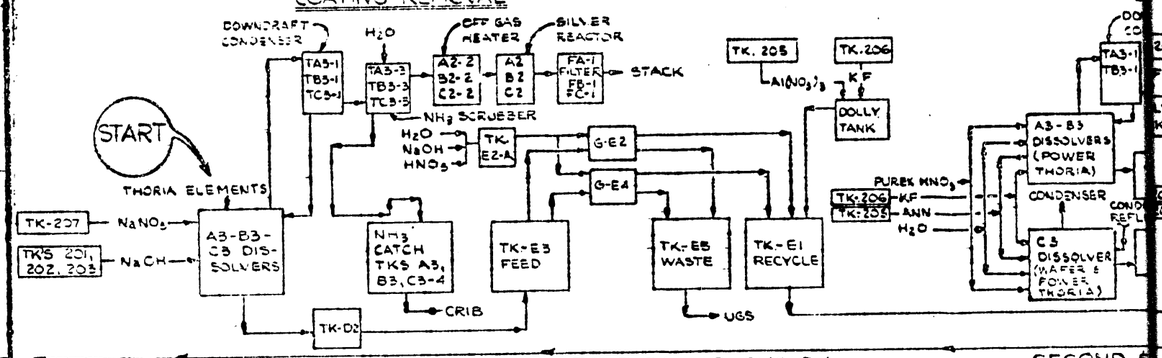
COATING REMOVAL



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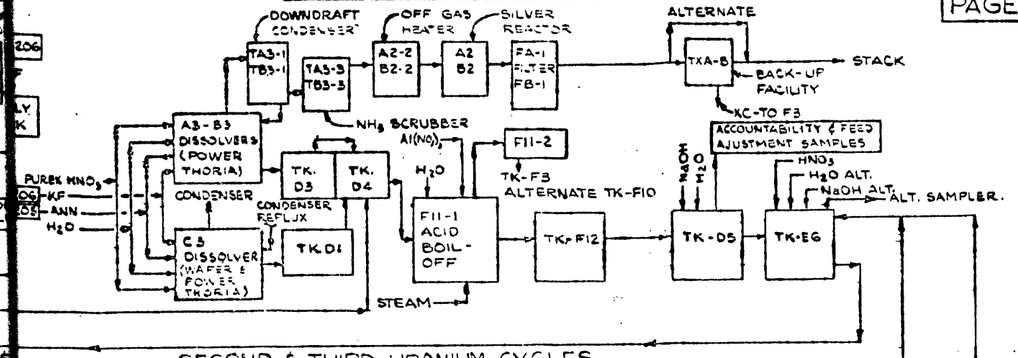
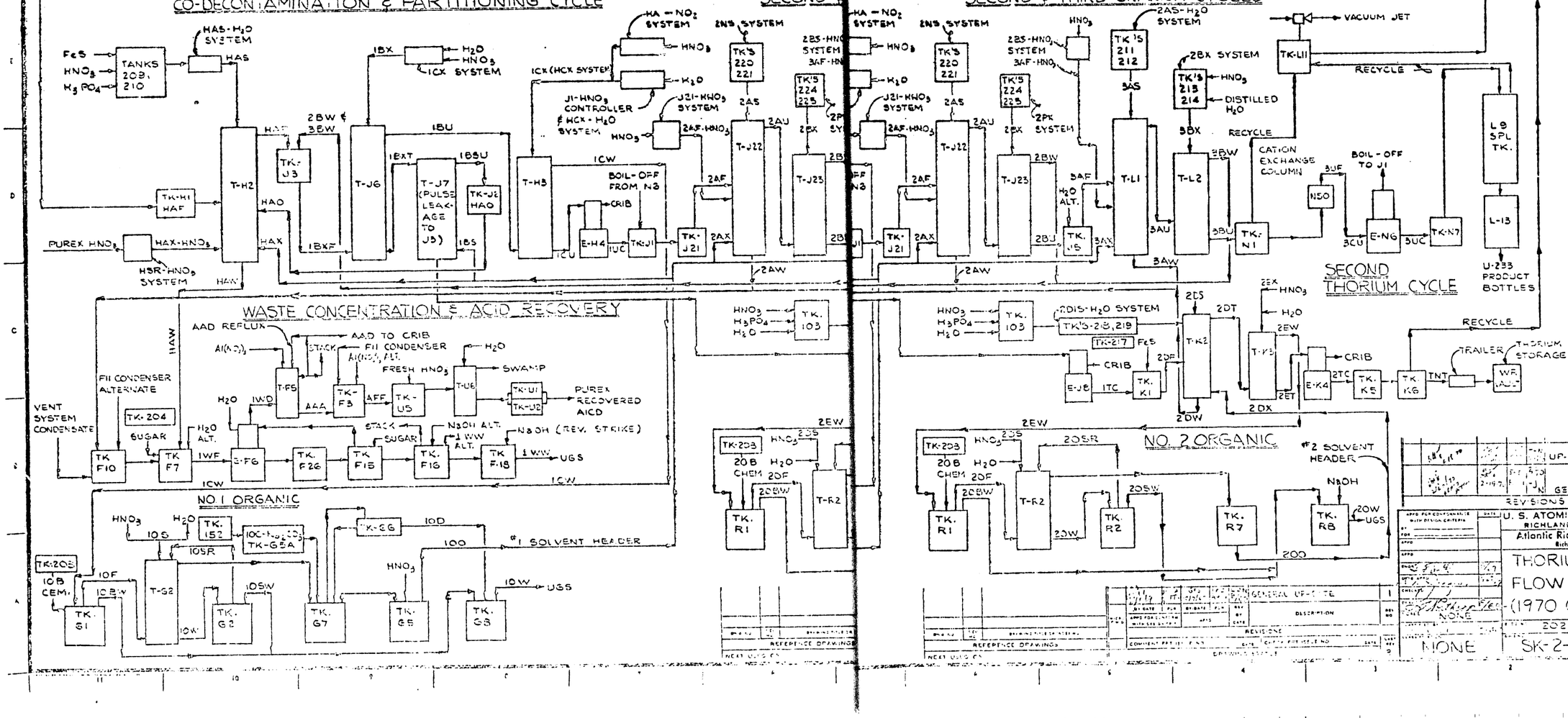


CO-DECONTAMINATION & PARTITIONING CYCLE

SECOND & THIRD URANIUM CYCLES



REVISIONS			
UP-DATED			3
GENERAL UP-DATE			2
GENERAL UP-DATE			1

U. S. ATOMIC ENERGY COMMISSION
RICHLAND OPERATIONS OFFICE
Atlantic Richfield Hanford Company
Richland, Washington 99352

THORIUM PROCESS FLOW SKETCH (1970 CAMPAIGN)

NONE

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