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# PRELIMINARY SAFETY STUDIES FOR PROPOSED FLUORINEL PROCESS

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DATE PUBLISHED–OCTOBER 1975

PREPARED FOR THE
UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
IDAHO OPERATIONS OFFICE
UNDER CONTRACT E (10-1)-1375 S-72-1

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# PRELIMINARY SAFETY STUDIES
# FOR PROPOSED FLUORINEL PROCESS

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Date Published - October 1975

Prepared for the
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ABSTRACT

Preliminary safety studies based on the Preliminary Design Criteria (ACI-168) are given for the proposed Fluorinel Process. A large number of abnormal occurrences are postulated and evaluated for safety considerations. Based on the safety evaluation, items requiring additional technical support work or more design detail are identified.

## SUMMARY

Safety studies are presented for the Fluorinel Process proposed for installation at the ICPP to process various classified and special reactor fuels. The conceptual process proposed in the Preliminary Design Criteria (ACI-168) has been studied and a table of postulated abnormal occurrences is presented. Each occurrence is evaluated for causes, safeguards, method of detection, correction and significant consequences of the accident. Based on evaluation of the abnormal occurrences, a list of technical support work required to determine significant consequences of certain potential accidents is given. Also given is a list of items requiring additional design detail to insure adequate safeguards or detection methods. These safety studies will provide useful input for preparation of the Preliminary Safety Analysis Report and identification of major safety hazards associated with the Fluorinel Process.

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# 1. INTRODUCTION

A wide variety of irradiated nuclear fuels is scheduled for reprocessing at the Idaho Chemical Processing Plant (ICPP) in accordance with the ICPP Multiple Fuels Processing Program (MFPP). A significant quantity of the fuels listed in the MFPP require special fuel handling and dissolution techniques. Information concerning some of the fuels is classified[1]. The existing facilities at the ICPP are not adequate for proper fuel handling during receipt, storage and transfer, and for the special dissolution requirements. The Fluorinel Process will provide a fuel storage basin addition and modifications, new fuel transfer and handling equipment, and installation of a new headend system.

Preliminary design criteria[2] have been prepared and conceptual design cost estimate work is presently in progress for the project. The preliminary safety studies work presented in this document have been completed to: (1) identify the main safety hazards associated with the conceptual process, (2) determine any additional development or technical support work needed to assure a safe system, (3) identify any additional equipment or safety systems needed in the conceptual design, and (4) provide useful input for preparation of the Preliminary Safety Analysis Report.

## 2. CONCEPTUAL PROCESS DESCRIPTION

The proposed conceptual process for the Fluorinel Project will require additions and modifications at the CPP-603 storage basin, new equipment for fuel cluster handling and transfer, a new headend system in CPP-601, and a special analytical system. The existing solvent extraction and waste systems in CPP-601 will be used.

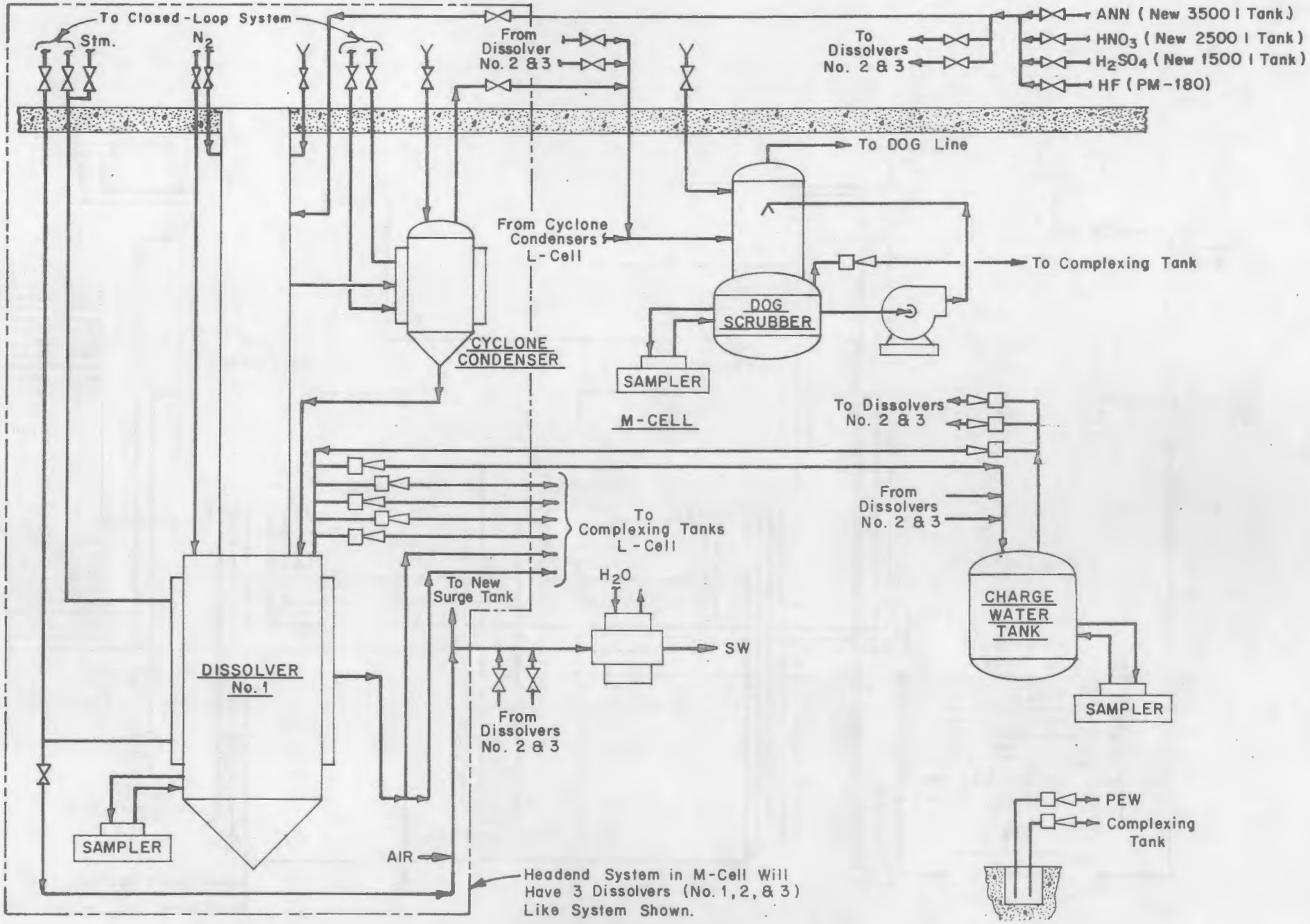
Fuel clusters for this process will be received and stored at CPP-603 fuel storage facility. Fuel will be transported from CPP-603 in a shielded cask and transferred to a hot cell in the CPP-601 PM area. Clusters will be charged batch-wise to one of three large dissolvers located in M cell. Dissolution will normally be accomplished in two steps by using an acid solution and then aluminum nitrate. Dissolver product will overflow to L cell for complexing with additional aluminum nitrate and for solids removal. Two centrifuges located in a hot cell will be used to remove solids which will be sealed in containers for subsequent disposal. Uranium extraction will be accomplished using existing facilities at the ICPP.

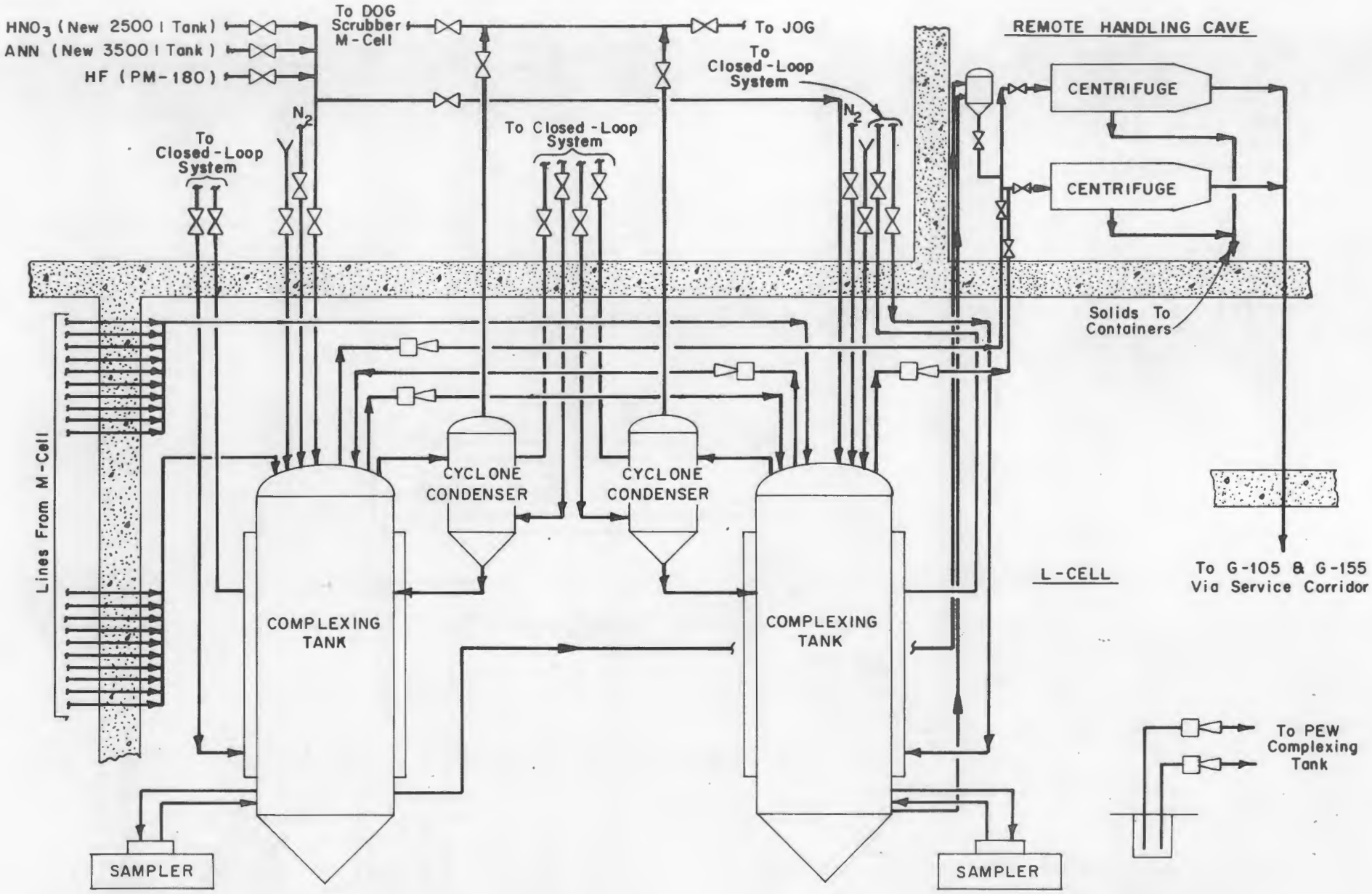
General equipment needs and modifications required for this process include: (1) a new fuel transport cask with necessary fuel and cask handling equipment, (2) hot cell in CPP-601 above M and L cells, (3) M cell headend system including three dissolvers and off-gas equipment, (4) L cell headend system including two complexing tanks and two centrifuges for solids removal, (5) solids handling equipment to centrifuge and package solids for disposal, (6) chemical makeup tanks and associated equipment in PM area, and (7) an analytical sampling and analysis system to provide rapid analytical results. Equipment flowsheets are shown in Figures 1 and 2.

### 2.1 Fuel Cluster Handling and Transfer.

The various fuel clusters which are to be processed are unloaded and stored underwater at the CPP-603 Fuel Receiving and Storage Facility.

The following procedure will be used to load fuel stored in the storage basin for processing. The new 25-ton fuel cask will be lifted from a horizontal to a vertical position and outriggers will be attached to the cask lid. The cask lid will be unsecured and the cask will be lowered into a new transfer pool located adjacent to the CPP-603 north basin. A framework structure will disengage the cask lid as the cask is lowered. The cask will be moved horizontally underwater to clear the cask lid. The fuel clusters will be removed from storage casks in the south basin with the modified transfer crane and placed in the temporary storage rack in the northwest corner of the basin. A new hoist will lift the clusters from the temporary storage rack and transport the fuel to the new transfer pool via the CPP-603 transfer canal. The fuel cluster will be lowered vertically into the cask. The transfer crane and fuel hoist will be connected and disconnected from the fuel using underwater tools, as necessary. The cask will be removed from the transfer pool and rotated to a horizontal position by reversing the procedure described. Decontamination of the cask will be performed as necessary.


To Closed-Loop System
Stm.
$N_2$
From Dissolver No. 2 & 3
To Dissolvers No. 2 & 3
ANN ( New 3500 l Tank )
$HNO_3$ ( New 2500 l Tank )
$H_2SO_4$ ( New 1500 l Tank )
HF ( PM-180 )
To DOG Line
From Cyclone Condensers L-Cell
To Complexing Tank
DOG SCRUBBER
CYCLONE CONDENSER
SAMPLER
M-CELL
To Dissolvers No. 2 & 3
From Dissolvers No. 2 & 3
To Complexing Tanks L-Cell
$H_2O$
To New Surge Tank
SW
CHARGE WATER TANK
SAMPLER
DISSOLVER No. 1
From Dissolvers No. 2 & 3
SAMPLER
AIR
Headend System in M-Cell Will Have 3 Dissolvers (No. 1, 2, & 3) Like System Shown.
PEW
Complexing Tank


HNO3 (New 2500 l Tank)
ANN (New 3500 l Tank)
HF (PM-180)
To DOG Scrubber M-Cell
To JOG
To Closed-Loop System
N2
To Closed-Loop System
To Closed-Loop System
N2
REMOTE HANDLING CAVE
CENTRIFUGE
CENTRIFUGE
Solids To Containers
Lines From M-Cell
CYCLONE CONDENSER
CYCLONE CONDENSER
COMPLEXING TANK
COMPLEXING TANK
L-CELL
To G-105 & G-155 Via Service Corridor
To PEW Complexing Tank
SAMPLER
SAMPLER

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The loaded cask will be lifted from the CPP-603 floor using a 30-ton straddle carrier, secured as necessary, and transported to the CPP-601 PM area. The cask will be placed on the PM area floor just south of L cell. A new 35-ton crane with load bar and hooks will be used to lift the cask and place it on the air bearing pad. The air bearing pad will be moved to seal the cask against the south wall of the hot cell. Slide doors in the cask and hot cell will be opened. Manipulators and remote handling tools will be used to attach a winch cable to the end of the fuel cluster inside the cask. The fuel will be pulled from the cask onto a receiving table using the power winch. The fuel will be lifted from the table using an overhead crane and placed in storage racks.

For TRIGA, and possibly PBF fuel, the removal of graphite end pieces will be required prior to processing. Hot cell manipulators will be used to place the fuel elements in a holding jig and operate a power saw or shear to cut the fuel.

Fuel will be charged to the dissolvers by dropping small elements with manipulators and by lowering heavy clusters with the overhead crane. The large clusters will be charged by attaching a release mechanism between the crane hook and the fuel cluster, opening the appropriate dissolver slug-chute valve, lowering the fuel into charge water to the bottom of the dissolver, releasing the fuel cluster, removing the release mechanism from the dissolver, and resealing the slug chute valve.

## 2.2 Dissolution System

2.2.1 Standard Fuels. After one of the Hastelloy dissolvers has been charged with fuel, the charging water (except for a 200 liter heel) will be transferred back to a hold tank. The dissolver vessel will then be purged with nitrogen to eliminate the possibility of forming explosive hydrogen-oxygen mixtures. Fuel dissolvent (normally hydrofluoric acid with 12 g/l cadmium added as a soluble nuclear poison) will be fed continuously to the dissolver at rates up to 500 l/hr. While the dissolver is filling, its contents will be heated to 60-70°C with the closed-loop system to initiate the exothermic dissolution reaction. During dissolution, the solution temperature will be controlled by circulating cooling water from the closed-loop system in the dissolver jacket. Solids in the dissolver bottom will be continually agitated by sparging with nitrogen. The dissolver product will overflow from the dissolver vessel and be airlifted with nitrogen to one of two complexing tanks.

When hydrogen evolution from the dissolver decreases significantly, the HF dissolvent flow will be stopped. The dissolver solution in the dissolver and complexing tank will be heated to about 80°C with the closed-loop system until samples indicate that the first dissolution step is complete. If no stainless steel components from the fuel clusters are present, the dissolver solution including any undissolved solids will be transferred to the appropriate complexing tank. If stainless steel components are present in the fuel clusters, the dissolver product from the hydrofluoric acid step will be emptied to a level just above the fuel support plate to allow the stainless steel and any other undissolved solids to remain in the dissolver bottom. The dissolver will be flushed with charging water several times to dilute the residual dissolver product solution to less than 0.5 $\underline{M}$ $F^-$.

Any stainless steel components will be dissolved with a solution of 6 M $H_2SO_4$-12 g/l Cd. The dissolver solution will be heated to boiling by supplying steam directly to the dissolver jacket. When dissolution of the stainless steel is complete, the entire dissolver contents including undissolved solids will be transferred to the complexing tank.

Prior to transferring dissolver product from the dissolver vessel, adjustment solution including hydrofluoric acid, aluminum nitrate, and nitric acid (all containing 12 g/l Cd) will be added to the complexing tank to improve solution stability, complex fluoride, and adjust solution for extraction. All solution collected in the complexing tank will be heated to about 80°C using a closed-loop system until samples indicate that uranium dissolution is complete. Uranium accountability samples will be taken from the complexing tank. When results of the accountability samples are received and system heel calculations are completed, the next batch of fuel can be charged to the dissolver.

The feed solution from the complexing tank will be fed through one of two centrifuges to remove insoluble particulate. The centrifuged solids will be dried if necessary, placed in sealed containers, checked for uranium, and removed from the hot cell for disposal if insignificant uranium is present. If significant quantities of uranium are present, the solids will be recycled to the dissolver. Clarified feed from the centrifuge will be collected in G-105 and G-155 for processing in the solvent extraction system.

During a processing campaign, occasional dissolver or complexing tank heel cleanouts may be required due to uranium heel calculations or a buildup of various undissolved solids. Uranium heels will be dissolved with the standard hydrofluoric acid and aluminum nitrate dissolvents. Solutions will be adjusted in the complexing tank to required specifications for processing through the first-cycle extraction system.

A classified flowsheet and detailed operating procedure for a typical aqueous halide fuel has been prepared[3].

2.2.2 PWR, TRIGA, and TORY. Three special fuels (PWR, TRIGA, and TORY) are presently identified for processing in the Fluorinel System. Other special fuels (such as PBF) scheduled for reprocessing at the ICPP may be identified for this system at a later time.

Laboratory development work is presently in progress for the PWR, TRIGA, and TORY fuels. A brief description of each fuel and the present conceptual processes are given in this section. Detailed flowsheets and process descriptions have been prepared for these fuels[3].

2.2.2.1 PWR Fuel. PWR fuel is a Zircaloy clad fuel containing $ZrO_2$-$UO_2$-CaO wafers. The clusters are 7-3/8 in. square x 97 in. long and weigh about 600 pounds. Poison plates in the fuel contain boron-stainless steel wafers and Inconel-X spacer rings.

Due to slow dissolution rates, PWR fuel will be dissolved in alternate batches using the two Hastelloy dissolvers. The HF dissolution step, which is normally rapid, will be scheduled so only one dissolver is producing large quantities of hydrogen gas at one time.

The general process method is described in the following steps:

(1) Charge one cluster to each Hastelloy dissolver.

(2) Add a batch of 6.8 M HF containing 12 g/l Cd to one dissolver to dissolve the Zircaloy cladding. Maintain dissolver solution at 60-70°C using closed-loop system.

(3) When decladding is complete in first dissolver, start step 2 for second dissolver.

(4) Add a small volume of $HNO_3$ containing 12 g/l Cd to make dissolver solution 0.5 M $HNO_3$ and dissolve $ZrO_2$-$UO_2$-CaO wafers.

(5) Heat dissolver solution to boiling. During this step, extra hydrofluoric acid will be added to maintain the F/Zr ratio at about 5.1 for dissolution of $ZrO_2$.

(6) Empty dissolver by transferring solution to complexing tank leaving about a 175-liter solution heel, undissolved stainless steel wafers and pins, Inconel-X rings and possibly a small percentage of the $ZrO_2$-$UO_2$-CaO wafers.

(7) Complete several batches of fuel in each dissolver. If a small percentage of undissolved $ZrO_2$-$UO_2$-CaO wafers remains in each batch, they will dissolve during the succeeding dissolution.

(8) Complex and adjust solution in complexing tank for solvent extraction.

(9) Flush dissolver with charge water several times to dilute the dissolver product heel and leave undissolved material in dissolver.

(10) After several more batches in each dissolver, an additional 6 M $H_2SO_4$ (12 g/l Cd) step will be completed to dissolve the stainless steel wafers and pins that have accumulated. This solution will be added to dissolver product and adjusted for solvent extraction.

2.2.2.2 TRIGA Fuel. TRIGA fuel will be received with both aluminum and stainless steel cladding and each type will contain zirconium-uranium hydride. The fuel elements are 1.47 in. diam x 28.44 in. long. There is a 4 in. graphite plug at each end of the fuel element which will be cut off prior to dissolution. The general process methods are described

in the following steps.

For stainless steel clad fuels:

(1) Cut graphite ends from fuel elements in the hot cell.

(2) Charge 38 elements to one of the Hastelloy dissolvers.

(3) Add 6 M $H_2SO_4$ containing 12 g/l Cd to dissolver and heat to boiling.

(4) Empty dissolver leaving fuel rods in dissolver.

(5) Add hydrofluoric acid containing 12 g/l Cd to dissolver to dissolve the zirconium hydride. Maintain at 80°C using closed-loop system.

(6) Add aluminum nitrate-chromic acid containing 12 g/l Cd to dissolver solution to dissolve $UF_4$ precipitate and complex the product. Heat solution to 60-70°C.

(7) Empty dissolver to the other complexing tank.

(8) Recharge dissolver (steps 1 and 2).

(9) Jet sulfuric acid in complexing tank back to dissolver for stainless steel decladding.

(10) Repeat steps (4) to (7).

(11) Complete dissolution of ten fuel batches using same sulfuric acid (intermittently stored in one complexing tank) for each batch and collecting the dissolver product in the other complexing tank.

(12) After ten batches, add the sulfuric acid to the dissolver product and adjust as necessary in preparation for solvent extraction.

For aluminum clad fuel:

Process ten batches of fuel using steps (1), (2), (5), (6), and (7) above and adjust with nitric acid for solvent extraction.

2.2.2.3 TORY Fuel. TORY fuel consists of $BeO-UO_2$ ceramic, has no cladding and will be received in aluminum cans. Initially, the cans will be 4-1/2 in. diam x 22 in. long, but future cans may be longer. The general process method is described in the following steps:

(1) Charge cans to the Inconel dissolver.

(2) Add 6.4 M $HNO_3$-.007 M Hg containing 12 g/l Cd to the dissolver and heat to dissolve the aluminum.

(3) Empty dissolver leaving about a 175 liter heel and add charge water to dilute heel and undissolved solids.

(4) Add 6 M $H_2SO_4$-1 M $HNO_3$ containing 12 g/l Cd to the dissolver and boil to dissolve the BeO-$UO_2$ ceramic.

(5) Empty the dissolver to the complexing tank and adjust for solvent extraction.

## 2.3 Dissolver Off-Gas System

The normal off-gas flow rate will be about 30 to 50 scfm from the dissolvers and 10 to 30 scfm from the complexing tanks. The high rate of $H_2$ gas evolution in the dissolver causes severe foaming. The off-gas from each dissolver and complexing tank will pass through separate cyclone-condensers to break up mist/foam and condense liquid from the off-gas streams. Liquid from the cyclone-condensers will drain back to each vessel. A scrub column with recirculating aluminum nitrate solution will be used to scrub hydrofluoric acid fumes from the off-gas and complex any entrained liquid not previously removed. The scrubbed off-gas from the M cell dissolvers will enter the CPP-601 E cell DOG system enroute to the ICPP stack. During uranium dissolution in the complexing tanks, the complexing tank off-gas may be valved to the C&D DOG line and routed through the Rare Gas Recovery Facility at CPP-604. The scrub solution will be sampled periodically to determine when replacement with fresh aluminum nitrate is necessary. Spent aluminum nitrate will normally be added to an adjusted batch of dissolver product.

## 2.4 Analytical Requirements

Operation of the Fluorinel headend system will be monitored by periodic and continuous sample analysis of various process solutions, chemical makeup solutions, the dissolver off-gas stream, and insoluble solids.

Chemical solutions made up in the CPP-601 PM Area will be sampled to check that each solution is made up to the proper specifications. Solutions "out of specs" will be adjusted and resampled. The hydrofluoric acid dissolvent will be continuously monitored with cadmium monitoring systems to assure dilution of the soluble neutron poison has not taken place.

During operation of the dissolver(s), a side stream of the dissolver off-gas will be continually analyzed for oxygen and hydrogen concentrations with an in-line analyzer system. The analyzer system will warn operating personnel of potential explosive hydrogen-oxygen mixtures. The hydrogen concentration can also be used to monitor the progress of the hydrofluoric acid and sulfuric acid dissolution steps.

During dissolution steps in the dissolver and complexing tanks, periodic samples will be taken to determine the rate of change of certain metal concentrations in the product solution. When samples show that the rate of change is less than about 10% per hour, the dissolution step in progress will be terminated and the next processing step can proceed. In order to provide rapid analytical results for the samples, a special computer-coupled X-ray analyzer will be used.

Prior to solvent extraction, the dissolver product feed will be sampled to provide uranium values for accountability input and to check that the solution is properly adjusted for solvent extraction.

Centrifuged solids will be collected in aluminum containers in the hot cell. Filled solids containers will be placed in shielded assembly between the neutron source and the detector. A carriage drive unit may be necessary to allow the detector to scan the length of the sample. The source, detector with scanning drive, and sample holder assembly will be located inside the hot cell with provisions for remote removal. The electronics will be located outside the cave in an instrument cabinet. A study is in progress to verify the use of the assay system and to develop more detailed design criteria.

## 2.5 PM Area Equipment

Chemical solutions for the Fluorinel Process will be prepared in the CPP-601 PM Area.

All solutions used in the headend system will contain cadmium as the soluble nuclear poison for criticality control. Each solution make-up will be sampled and cadmium concentration determined by laboratory analysis. Each solution containing cadmium will be safeguarded against inadvertent dilution by strict control of all lines (quick disconnects, locking valves, etc.) entering the makeup tanks. In addition to the laboratory analysis, the cadmium concentration in the hydrofluoric acid will be verified by use of a dual cadmium monitor system. The cadmium concentration of other solutions including nitric acid, sulfuric acid, charge water, aluminum nitrate closed-loop solution, and heel cleanout solution will be guaranteed by use of special procedures requiring supervisory approval and signoff in addition to laboratory analysis.

2.5.1 Closed-Loop Systems. Three independent closed-loop systems using Cd as a soluble nuclear poison will provide heating and/or cooling for the three M cell dissolvers, the two L cell complexing tanks, and dissolver and complexing tank condensers. The Cd in the water will provide a secondary criticality safeguard by preventing a decrease in the cadmium concentration in the dissolver or complexing tank solutions, should any of the vessels become perforated due to corrosion or other causes. A liquid level alarm on each surge tank will detect any internal leaks from the heat exchangers. Cadmium nitrate will be added to water in each surge tank and the Cd concentration will be verified by sample analysis.

## 3. SAFETY DESIGN CONSIDERATIONS

### 3.1 Criticality Safety

Since the equipment in the Fluorinel Process is not designed to be geometrically safe and is not provided with fixed nuclear poisons, criticality safety will be maintained by strict nuclear, operational and administrative controls. Tentative control limits have been chosen as listed below for preliminary design purposes.

(1) The combined system heel will not exceed 50 kgs U-235 on a before-burnup basis. A method of calculating a running uranium material balance for the system will be required.

(2) The dissolver charge water, HF dissolvent, sulfuric acid, nitric acid, aluminum nitrate, and the closed-loop system water will each contain a specified minimum cadmium concentration. The cadmium concentration of each solution will be determined by laboratory analysis. Each solution will be safeguarded against dilution by strict control of all lines entering makeup tanks.

(3) The fuel charge to a dissolver for each batch will not exceed 28 kgs total uranium on an after-burnup basis.

(4) Two cadmium detector units will be used to continuously monitor the cadmium concentration for HF dissolvent.

(5) A limit of 28 kgs of uranium on an after-burnup basis will be set for the hot cell. Fuel clusters will be stored in racks to hold elements in a critically safe array.

Based on process flowsheet conditions, equipment design, and nuclear controls, criticality safety calculations will be made for individual vessels and the overall system. Final mass limits and operating controls will be based on detailed design studies.

### 3.2 Hydrogen-Oxygen Mixtures

During dissolution, large quantities of hydrogen are given off by the chemical reaction. To prevent possible explosion, the oxygen concentration of the dissolver off-gas will be maintained below 4%. No air sources to the dissolver will be allowed, and all purges will be nitrogen. An oxygen analyzer will continuously monitor the off-gas.

Prior to fuel charging, the hydrogen concentration of the dissolver off-gas must not exceed 3%. Residual hydrogen from the previous batch and air entering the open slug chute could form an explosive mixture. Following completion of a batch, excess hydrogen will be nitrogen-purged from the dissolver and a hydrogen analyzer will be used to monitor the off-gas.

### 3.3 Fuel Charging

The Fluorinel System will process a number of large fuel clusters possibly weighing up to 2,600 pounds. Since the routine method of dropping fuel (through charging water) into the dissolver is not desirable for large clusters, a method of lowering fuel from the charging cave to the bottom of the dissolver is being proposed. Since accidental dropping of a large cluster while lowering is possible, the dissolver design (crash plate, vessel supports, etc.) must be evaluated to insure damage will not occur.

## 4. SAFETY ANALYSIS

The Fluorinel Process described briefly in this document and in more detail in the Preliminary Design Criteria (ACI-168), has been evaluated to determine a number of hazards associated with the proposed process which have a potential bearing on safety. The operation of all systems in the conceptual process was analyzed to determine any abnormal occurrences that could occur from equipment malfunctions, operating conditions, or operator error. Each abnormal occurrence is specified in Table I and has been evaluated to determine; (1) possible causes for the occurrence, (2) primary and secondary safeguards to prevent an accident from occurring, (3) method(s) of detecting a potential accident condition, (4) steps required to correct the situation and minimize the accident consequences, and (5) the possible consequences of the accident on the system being studied and any related systems including effects on associated persons. All abnormal occurrences envisioned have been included in the table even though some may be incredible (technically conceivable but practically impossible) or would result in no significant consequence on process or personnel.

Based on evaluation of the abnormal occurrences, some technical support work that would be required to determine if the postulated accident would cause significant consequences to systems or personnel have been identified. These items are listed as follows:

(1) Effect of dropping transfer cask during handling operations at CPP-603 and CPP-601 PM Area.

(2) Effect of dropping heavy fuel clusters during handling operations.

(3) Criticality calculations for various fuel arrays in CPP-603 basin and the hot cell.

(4) Calculations for fission product release from damage fuels in CPP-603 basin.

(5) Shielding calculations for fuel transfer cask, solids transport cask, and the hot cell.

(6) Effect of ramming cask into basin or hot cell walls.

(7) Effect of liquid moderation on hot cell criticality safety.

(8) Criticality calculation for charging excess fuel to dissolver.

(9) Effect of dropping heavy fuel into dissolver with no charge water present.

(10) Criticality calculations for dilution of Cd concentration in various solutions.

TABLE I

POSTULATED ABNORMAL OCCURRENCES FOR FLUORINEL PROCESS

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Fuel Loading | Drop cask on to CPP-603 floor | Operator error | Trained operator using approved procedures | Cask designed to withstand accidental drop | Visual | Monitor cask, inspect and repair equipment and facilities | Damage to cask or CPP-603 floor | |
| | | Equipment failure | Equipment designed for heavy loads | Regular inspection and maintenance of equipment | | | | |
| | Ram cask into basin wall | Operator error | Trained operator using approved procedures | Cask designed to withstand accident | Visual | | Damage to basin wall or cask | Release of contaminated water to ground |
| | | Malfunction of control unit | Cask should be high enough to clear wall by procedure | Emergency shut off switch on control | | | | |
| | Drop cask onto basin floor | Equipment failure | Equipment designed for heavy loads | Regular inspection and maintenance of equipment | Visual | | Damage to basin floor or cask | |
| | Drop fuel onto basin floor | Lifting equipment failure | Equipment designed for heavy fuels | Regular inspection and maintenance of equipment | Visual | Retrieve fuel, check for damage | Damage to fuel or basin floor | |
| | | Failure of fuel attachment | Attachment designed for weight of fuel | Insignificant damage to fuel or floor should result | | | Release fission products to water | |

TABLE I (Cont.)

POSTULATED ABNORMAL OCCURRENCES FOR FLUORINEL PROCESS

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Fuel loading (Cont.) | Drop fuel onto basin floor | Operator error | Trained operator | Equipment designed to withstand accidental bumping, etc. | Visual | Retrieve fuel, check for damage | ↓ | ↓ |
| | Fuel dropped on storage rack or bucket | Lifting equipment failure | Equipment designed for heavy fuels | Regular inspection and maintenance of equipment | Visual | ↓ | Damage to fuel, racks, or bucket. Need calcs for criticality | |
| | | Failure of fuel attachment | Attachment designed for weight of fuel | Insignificant damage to fuel or floor should result | ↓ | | ↓ | |
| | | Operator error | Trained operator | Equipment designed to withstand accidental bumping, etc. | | | | |
| | Fuel lifted beyond limit of basin water shielding | Operator error | Trained operator using approved procedures | Limit switch on crane | Visual. Need radiation detector covering all fuel handling areas | Lower fuel into water | Personnel exposure | |
| | | Hoist control manfunction | Limit switch on crane | Emergency shut off switch | | | | |
| | Fuel above safe shielding limit of water | Low basin water level | Procedures require water at certain level | Liquid level alarm | Visual markers and level alarm | Lower fuel and add water to basin | Personnel exposure | |

TABLE I (Cont.)

POSTULATED ABNORMAL OCCURRENCES FOR FLUORINEL PROCESS

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Fuel loading (Cont.) | Fuel will not fit in cask | Fuel damaged in accident | Trained operator handling fuel | Properly designed handling equipment | Visual | Improve special procedures | Delay operation | |
| | | Fuel not cut properly | Cask will handle all fuels uncut | None | | Return to ECF for cutting | | |
| | Fuel to be loaded is passed over other stored fuel in basin | Operator error | Trained operator using approved procedures | None | Radiation alarm | Evacuate | Possible criticality. Need data. | |
| | Lower cask into basin framework without removing lid securing device | Operator error | Trained operator using approved procedures | Equipment design | Visual | Raise cask and remove lid securing device | Damage to cask or framework | |
| | Cannot disengage crane hook from fuel loaded in cask | Hook closure stuck | Equipment design simple | Regular inspection | Visual | Use various fuel handling tools and special procedures | Delay operation | |
| | | Fuel attachment device will not rotate | Equipment design | Hook can normally be disengaged without rotation | | | | |
| | | Operator loads fuel improperly | Trained operator | Easy to reposition fuel | | | | |

TABLE I (Cont.)

POSTULATED ABNORMAL OCCURRENCES FOR FLUORINEL PROCESS

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Fuel loading (Cont.) | Fuel cask lid dropped on fuel loaded in cask | Equipment failure | Equipment design | Regular inspection | Visual | Retrieve lid check for damage and repair as necessary | Damage cask, cask lid, or fuel. Release F.P. to water | |
| | High radiation level outside cask when removed from water | Lid not sealed | Operator follows procedures | Cask monitored by HP as removed from water | Radiation alarm HP monitor cask | Adjust lid | Personnel exposure | |
| | | Slide valve open | Procedures require check of valve | | | Close and secure slide valve | | |
| | Basin water does not drain from cask. | Cask drain restricted | Drain not easily restricted | Two drains | Water leak during transport or when slide valve opened | Clear drain | Contamination of CPP-603 area | Contamination of straddle carrier roadway, or CPP-601 PM Area. |
| | Fuel exposed in air | Cask dropped or rammed into wall of basin | Approved procedures followed | Lid secured before moving cask | Visual | Improvise emergency procedures | Personnel exposure damage to cask or basin | |

TABLE I (Cont.)

POSTULATED ABNORMAL OCCURRENCES FOR FLUORINEL PROCESS

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Fuel cask transport | Drop cask from straddle carrier during transport | Operator error | Certified operator | Carrier operated at low speed. Cask designed to withstand accident | Visual | Check and survey cask. Repair equipment. | Damage to cask on straddle carrier | Contamination of roadway |
| | | Mechanical failure | Regular inspection and maintenance | | | | | |
| | Cask contaminated above limits during transport to PM area | Not properly cleaned at CPP-603 | Cask routinely cleaned after removal from basin | HP survey required before transport | HP survey of PM area and roadway | Clean cask and contaminated areas | Contamination of roadway and PM area | |
| | Ram straddle carrier into side of hot cell | Operator error | Trained operator | | Visual | Check straddle carrier and hot cell for damage | Damage to straddle carrier, cask or hot cell | |
| | | Mechanical failure | Routine inspection and maintenance | Emergency brake | | | | |

TABLE I

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Fuel transfer to CPP-601 | Drop cask on PM area floor | Equipment failure | Equipment design | Regular inspection and maintenance | Visual | Repair equipment | Damage to cask or floor | |
| | Ram cask into side of hot cell with crane | Operator error | Certified operator | Limit switch | Visual | Monitor cell and cask. Repair equipment | Damage to cask or hot cell | |
| | | Equipment malfunction | Simple reliable equipment | Emergency shut down switch | | | | |
| | Open hot cell slide valve without cask in place | Operator error | Certified operator following procedures | Lock on slide valve switch | Radiation alarms | Close slide valve | Personnel exposure | |
| | | Equipment manfunction | Safety interlock | Valve will fail | | | | |
| | Fuel stuck in cask | Fuel damaged | Fuel inspection on receipt | Trained operator handling fuel | Visual | Use special procedures or return cask to basin and check | Damage to hoist, fuel (attachment) or cask. | |
| | | Cask (rollers) damaged | Cask routinely inspected | Fuel normally removable if rollers damaged | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| | Hot cell slide valve closed on winch cable or fuel | Operator error | Certified operator | Lock valve open. Slide valve air to open and air to close. | Visual | Open valve | Damage to cable, fuel, or cell - slide valve. | |
| | | Equipment malfunction | Simple, reliable design | | | | | |
| | Fuel winch fails | Equipment failure | Routine inspection and maintenance | Winch remotely repairable or replaceable | Visual | Repair | Delay Operation | |
| | Place several fuel clusters on receiving table | Operator error | Certified operator following procedures | Supervision approval needed for transfer | Need monitor in cave | Place clusters in storage racks | Criticality? Need calculations | |
| | Remove cask before closing hot cell slide valve | Operator error | Certified operator | Safety interlock | Radiation alarm | Close slide valve | Personnel exposure | |
| Fuel transfer to CPP-601 Hot Cell | Exceed fuel limit in hot cell; criticality | Operator error | Certified operator and approved procedures; limit U | Clusters stored in racks to prevent critical arrays | Radiation alarm | Self limiting as geometry changes | Contamination of hot cell | Contamination of PM area |
| Hot Cell Operation | Drop or ram cluster against something in hot cell | Operator error | Certified operator | Design protection for vulnerable items | Visual | Check damage and repair as necessary | Damage to fuel or various hot cell equipment | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Hot Cell Operations (Continued) | | Equipment failure | Simple reliable design | Safety shutdown switch | ↓ | ↓ | ↓ | |
| | Loss of Hot Cell vacuum | Failure of VOG system | WL-509 jet very reliable | Blower WL-204 can be used | Pressure Alarm | Repair jet | Contamination of hot cell | Contamination of PM area |
| | | Large air leak into cell | Pre-operation check | Air will leak into cell - under vacuum | | Locate and repair leak | | |
| | Failure of manipulators | Dirt, corrosion, worn parts, etc. | Routine inspection and maintenance | Easily repairable or replaceable | Visual | Repair | Delay operation | |
| | Fuel cut in wrong place | Operator error | Certified operator | Cutting jig used to hold fuel | Visual | Recut if necessary. Repair equipment | Contamination to cave. Possible fire with TRIGA | |
| | | Equipment malfunction | Design should prevent failure from cutting in wrong location. | | | | | |
| | Leak in OG valve or line in hot cell | Corrosion | Use corrosion resistant materials | Valves replaceable | Alarm for high $O_2$ concentration in OG line | Replace or repair as necessary | Contamination to hot cell | |
| | | Hot cell accident | Certified Operator | Shield valves and lines? | | | | |
| | | Equipment failure - gasket, quick disconnect parts, etc. | Pre-operation tests for leaks, etc. | Valves repairable or replaceable remotely. | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Hot Cell Operation (Continued) | Damage from high pressure decon. spray | Operator error | Certified operator, approved procedures | Protection for vulnerable equipment, windows, etc. | Visual | Check damage and repair as necessary | Damage to windows, manipulators, crane cables and possibly other equipment | |
| | | Equipment failure | Emergency shut off switch | | | | | |
| Fuel Charging | Charge fuel to wrong dissolver | Operator error | Certified operator | Plugs to dissolver not in use are secured | No dissolution reaction | Use special procedures to remove fuel and recharge | Delay operation | |
| | Fuel will not lower into dissolver | Fuel jam | Procedures should insure each fuel is lowered to proper depth. | Upper acid line for dissolving jams | Visual | Remove fuel. Dissolve small batch. | Reduce throughput rate | |
| | Charge more clusters than on flowsheet | Operator error | Certified operator, approved procedures | Supervisor must verify correct charge | Check of fuel inventory; long dissolution period | Check dissolver heel. Use special procedures | Criticality calculations needed. | |
| | Fuel dropped while lowering into dissolver | Equipment failure | Equipment designed for heavy load | Dissolver will withstand accidental drop | Visual or audible | Repair equipment | | |
| | Fuel release mechanism will not work | Equipment malfunction | Equipment design | Mechanism replaceable | Visual | Return fuel to cell and repair mechanism | Delay operation. Contaminate hot cell. | |

TABLE I. (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Fuel Charging (Continued) | Fuel dropped into dissolver with no charge water | Operator error | Heavy fuels normally lowered | Dissolver designed to withstand drop | Visual | Repair any damage | Need calculations for heavy fuels | |
| | Splash charge water into hot cell | Accidentally drop fuel | Large heavy fuels normally lowered | Equipment designed for heavy fuel | Visual | Clean up water | Contaminate hot cell | |
| | Charge fuel without cutting (TRIGA) | Operator error | Certified operator | Supervisor approval required | Visual | Dissolve or remove end pieces | Delay operation | |
| | Slug chute plug leaks | Bad gasket or seal | Simple plug design | Plug easily replaceable | Dissolver pressure alarm | Reseal plug. Repair or replace if necessary. | Delay operation | |
| | Bridge crane fails with fuel attached | Equipment failure | Routine maintenance | 35-ton crane can be used to move fuel and remove crane for repair | Visual | Remove hot cell roof. Use 35-ton crane to move fuel and remove crane for repair | Delay operation | |
| PM Area Operations | Acid leak from PM-tank or piping | Corrosion or damage to rubber liner in HF tank | Selection of corrosion resistant materials | Routine inspection and maintenance | Visual, Sump alarm | Repair leak | Subject personnel to acid vapor or acid burns | |
| | Incorrect chemical makeup | Operator error | Certified operator, approved procedures | All solutions sampled | Sample or Cd monitor | Adjust makeup | Delay operation | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| PM Area Operations (Continued) | Loss of closed loop system water circulation | Pump failure | Regular inspection and maintenance | Pump easily replaceable | Dissolver on comp. tank solution temp. alarm | Repair pump | Delay operation | |
| | Loss of HF tank agitator propeller | Corrosion | Corrosion resistant material | Periodic inspection and maintenance | No agreement between sample and monitor. Monitor alarm | Repair agitator | Delay operation. Damage tank rubber liner | |
| | Dilution of Cd in PM makeups after sample | Operator error | Certified operator | Supervisor check of locked valves for transfers | Cd monitor for HF. No monitor for other solutions | Adjust makeup solution | Criticality calculations | |
| | | Solution leak into vessel | All lines have locking valve or disconnect | No gravity feed lines | | | | |
| | Incorrect reading of HF Cd monitor | Equipment malfunction | Use dual monitor | Solution analyzed and administrative control of lines | Alarm on monitor | Check instrument. Resample if necessary | Delay operation | |
| | HF flow control valve not controlling | Corrosion or other failure | Corrosion resistant material used | Manual valve can be used. Control valve replaceable | High or low HF flow rate | Use manual valve. Repair control valve | Fast dissolution rate. Delay operation. | |
| | PM solutions leak to in-cell vessels | Valve failure | Corrosion resistant material used | At least two valves on each drain line & locks | PM tank level decreasing | Repair valve | High corrosion rate in vessels. Form ppt. | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| PM Area Operations (Continuous) | Chemical transfer pump failure | Corrosion or worn parts | Regular inspection and maintenance | Spare parts and pumps on hand | No solution transfer | Repair or replace pump | Delay operation | |
| | Leak of solution or water in heat exchanger | Corrosion | Corrosive solution not used | Exchanger Const. of SST | High level alarms in surge tank | Shut down and repair leak | Dilution of Cd | |
| | | Faulty weld | Equipment pressure tested | Routine inspection and maintenance | | | | |
| | Cannot control dissolver or comp. tank temperature | Failure of heat exchange stm control valve | Pre-operation checks | Valve easily replaceable | Temperature Alarm | Repair or replace valve | Delay operation | |
| | Personnel contact with Cd compounds | Operator error | Certified operator | Operator will wear protective equipment | Overexposure will be obvious to victim | Seek medical aid | Cd very toxic | |
| | | Equipment failure | Equipment design | | | | | |
| | Add wrong chemical to dissolver or complexing tank | Operator error | Centified operator | Supervisor must unlock correct valve | Sample analysis | Adjust and remove solution as necessary | High corrosion rate of vessels. Form ppt. Delay operation | |
| | Add wrong amount of chemical to dissolver or complexing tank | Operator error | Certified operator | All solutions sampled | Sample analysis | Readjust solution | Percipitate, Poor extraction, & corrosion | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Fuel Dissolution | Start dissolution with dissolver full of charge water | Operator error | Certified operator | Check off sheet | Reaction slow to start | Jet out water and start dissolution | Delay operation | Process extra waste solution. |
| | Charge fuel with high $H_2$ conc. in dissolver >3% | Operator error | Certified operator; approved procedure checksheet | Supervisor approval to charge needed | Alarm $H_2$ analyzer | $N_2$ purge dissolver to remove $H_2$ | $H_2$-$O_2$ explosion | |
| | | $H_2$ analyzer malfunction | Routine calibration | Duel analyzers | | | | |
| | Start HF with high $O_2$ conc. in dissolver >4% | Operator error | Certified operator | Check off sheet | Alarm on $O_2$ analyzer | $N_2$ purge dissolver | $H_2$-$O_2$ explosion | |
| | | $O_2$ analyzer malfunction | Routine calibration | Dual analyzers | | | | |
| | High liquid level in dissolver | Operator error, airlift not on | Certified operator | Check off sheet | High level alarm on dissolver | Turn on airlift | Pressurize dissolver | |
| | | Overflow lines plugged | Equipment designed to prevent solids carryover | Provision for clearing plugs | | Shut off acid; clear restriction | | |
| | HF flow rate too high | Operator error | Certified operator | High flow alarm | High flow rate alarm | Reduce HF flow rate | Pressurize dissolver | |
| | | Equipment malfunction | Manual control valve | Control system easily repaired | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Fuel Dissolution (Continued) | Transfer dissolver contents before first step complete | Operator error | Certified operator | Supervisor approval required | Uranium left in centrifuged solids | Recycle solids to dissolver | Reduce throughput rate | |
| | | Incorrect sample analysis | Certified analyst | Samples may not be needed as experience is gained | | | | |
| | | Unrepresentative sample | Certified operator using approved procedures to sample | | | | | |
| | Use cone jet with sst pins still in dissolver | Operator error | Certified operator | Lock on jet require supervisor approval | Solution will not transfer if jet plugs | Special instructions to dissolve sst | Plug jet and transfer line | |
| | Add $H_2SO_4$ without reducing $F^-$ M to <0.5 M | Operator error | Certified operator | Supervisor approval needed | None | Dilute dissolver solution | High corrosion rate on dissolver. PPT if Zr conc. too high | |
| | | Incorrect sample analysis | Certified analyst | Samples may not be needed. Dilution procedure adequate | | | | |
| | | | | | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Fuel Dissolution (Continued) | Steam leak from jacket to dissolver | Corrosion of vessel | Use of corrosion resistant material with corrosion allowance | Periodic inspection of corrosion coupons | High level alarm on dissolver | Shut off steam acid Cd | Criticality if Cd diluted enough. Need calculations | |
| | Transfer dissolver contents before $H_2SO_4$ step is done | Operator error | Certified Operator | Supervisor approval required | Jet may plug | Do $H_2SO_4$ heel out | Plug jet on transfer line | |
| | | Incorrect sample analysis | Certified analyst | $H_2$ generation will indicate complete dissolution | | | | |
| | Use wrong jet to completely empty dissolver | Operator error | Certified operator | Supervisor will approve and unlock correct jet | Level | | Leave large U heel in dissolver | |
| | Add incorrect amount HF to dissolver or complexing tank | Operator error | Certified operator | Supervisor check | Sample analysis | Add addition HF or ANN as required | F/Zr <4.8 PPT >6 corrosion | |
| | | Leak from HF tank | Corrosion resistant valves | Two valves min. on all acid lines | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Fuel Dissolution (Continued) | Add incorrect amount of ANN to complexing tank | Operator error | Certified operator | Supervisor check | Sample analysis | Adjust solution | Over complex - PPT, undercomplex-corrosion | |
| | | Leak from ANN tank | Corrosion resistant valves | Two valves | | | | |
| | Add incorrect amount of $HNO_3$ to complexing tank | Operator error | Certified operator | Supervisor check | Sample Analysis | Adjust solution | Too much acid - PPT, too little acid - poor extraction and PPT | |
| | | Leak from $HNO_3$ tank | Corrosion resistant valve | Two valves | | | | |
| | Loose seal on dissolver plug | Gasket damaged | Routine inspection | Plugs easily repairable or replaceable | Low vacuum alarm or high $O_2$ concentration alarm | Reseal plug Repair or replace plug | Delay operation $H_2$-$O_2$ explosion | |
| | | Plug not installed right | Vacuum checked after charge | Alarms on vacuum and $O_2$ conc. | | | | |
| | Leak from dissolver vessel to jacket | Vessel corrosion | Routine inspection of corrosion coupons | Jacket pressure >vessel pressure | Low level alarm in closed-loop surge tank | Shut down and repair dissolver | Acid dilution will slow dissolution | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Fuel Dissolution (Continued) | Leak from dissolver to cell | Vessel corrosion | Following approved procedures prevent high corrosion rates | Large corrosion allowance with periodic inspection | Cell floor sump alarm | | Contamination to cell | Release to stack and environment |
| | Failure of OG scrub pump | Corrosion, worn parts etc. | Routine inspection and maintenance | Provisions for easy repair or replacement | Low pressure alarm on discharge | Repair or replace pump | Corrosion of equipment downstream from $F^-$ | |
| | Loss of cooling water to condenser | Pump failure | Routine inspection and maintenance | Spare pump available | High OG temperature alarm | Repair or replace pump | None | |
| | | Not valved in | Certified operator | High temperature alarm | | Open appropriate valves | | |
| | Loss of dissolver vacuum | Failure of E DOG system | WN-552 jet reliable | | Low vacuum alarm on dissolver | | Pressurize dissolver | |
| | | Foam block in OG system | Procedures prevent excessive foaming | Equipment designed to handle high foam rate | | Reduce dissolution rate | | |
| | | Operator error | Certified operator | | | Valve in correct dissolver | | |
| | | Control system malfunction | Simple, reliable design | | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Fuel Dissolution (Continued) | Steam to jacket during HF dissolution | Operator error | Certified operator | Check sheet | High temperature dissolver solution | Shut off steam | | |
| | | Leak in valve | Backup valves | Valves replaceable | | | | |
| | Leak from charge water tank | Corrosion | Procedures prevent corrosive solution from tank | Tank const. of corrosion resistant material | Cell floor sump alarm | Repair leak | Contaminate cell | |
| | Loss of water to steam jacket on condenser | Operator error | Certified operator | Steam trap | High condenser outlet temperature | Turn on water | | |
| | | Utility failure | Periodic inspection and maintenance | | | Repair as necessary | | |
| | Leak from scrubber | Corrosion | Corrosion resistant material | Corrosion allowance | Cell floor sump alarm | Repair as necessary | Contamination to cell | |
| | | Worn pump seals | Routine inspection and maintenance | Pump easily repairable | | | | |
| | Airlift dissolver product to wrong complexing tank | Operator error | Certified operator | Supervisor unlocks valve on air supply to correct airlift | High level alarm on complex tank if wrong tank is near full | Switch to correct tank. Resample other tank and adjust as necessary | Delay operation | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Dissolution, complexing, and adjustment | Leak between complexing tank and jacket | Corrosion of vessel wall | Large corrosion allowance for vessel | Periodic inspection of corrosion compands. | Increase or decrease in level of closed loop surge tank | Shutdown and repair leak | Contamination of closed loop system | |
| | Leak in complexing tank to cell | | | | Cell floor sump alarm | | Contamination of cell | |
| Transfer complexing tank solution to centrifuge | Piping leak in hot cell | Corrosion of piping or valves | Large corrosion allowance | Periodic inspection | Floor sump alarm | Stop transfer and repair leak | Contamination of hot cell and equipment | |
| | | Failure of disconnect fitting | Use tested design of corrosion resistant material | Provision for remote repair | | | | |
| | Solution will not transfer from complexing tank | Solids restriction in piping or valves | Procedures to keep solids agitated and transfer lines purged | Provisions to flush all transfer lines | No solution transfer | Clear plug using freeze plugs and flush lines. Jet to other tank and transfer | Delay operation | |
| | Transfer rate too high for centrifuge | Operator error | Certified operator | Size jet, airlift and centrifuge for proper capacity | High amps alarm on motor | Reduce flow rate | Damage to centrifuge | |
| | | Failure of flow control device | Simple reliable design | | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Centrifugation | Centrifuge Inoperable | Equipment failure | Installed spare available | Provisions for remote repair or replacement | High amps alarm or will not run | Repair damaged unit | Delay operation | |
| | Drop solids container in hot cell | Operator error | Trained operator | Solids easily cleaned up | Visual | Clean up solids and return to container | Contamination to hot cell. Damage to cell equipment. | |
| | | Equipment failure of manipulators | Routine inspection and maintenance | | | | | |
| | Overfill Solids Container | Equipment failure | Level detection system with alarm | Periodic inspection required | Abnormal centrifuge operation | Install new container | Damage to centrifuge | |
| Remote Maintenance Operations | Drop centrifuge or replaceable valve assembly in hot cell | Operator error | Certified operator | | Visual | Inspect equipment and repair as necessary | Damage to equipment and piping in hot cell | |
| | | Failure of cave hoist equipment | Equipment design | Routine inspection and maintenance | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| M and L Cell Off-Gas Handling | Loss CPM DOG vacuum to complexing tank | Operator error | Certified operator | | High pressure alarm on complexing tanks | Correct error | | |
| | | Failure of DOG blower | Standby blower on automatic | WN-550 jet back-up on automatic | | Repair blower | | |
| | Loss of VOG vacuum to M and L Cell Vessels | Failure of WL-509 Jet | WL-209 blower can be used | | | Repair jet | | |
| | | Operator error | Certified operator | | | Correct error | | |
| | Loss of C-D DOG to complexing tank during operation of RGP | Operator error | Certified operator | | High pressure alarm on complexing tank | Correct error | | |
| | | Failure of RGP compressor | Backup compressor on automatic | Valve will bypass DOG to stack | | Repair compressor | | |
| Sampling PM Tanks | Solution leak in sample system | Corrosion | Proper materials of construction | Sampler enclosed or located over catch pan | Visual | Repair leak | Personnel contact with chemical solution or vapor | None |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Sampling PM Tanks (Continued) | Non-representative Sample | Operator error | Certified operator using approved procedures | Sampler designed for no liquid holdup | None except HF Cd monitors | Require several samples on Cd monitors | Criticality if Cd too low | None |
| | Incorrect analysis of Cd | Lab error | Certified analysts using approved procedures | Multiple samples with two analysis methods | HF monitor or 2nd analysis method | Reanalyze | Criticality | None |
| Monitor HF Solution | Failure of Cd monitor | Equipment malfunction | Dual monitors | Lab analysis | Alarm | Repair monitor | Delay Operation | None |
| Monitoring of DOG | Acid vapors not removed from DOG Sample Stream | Sample scrubber failure | Routine inspection | Scrubber in hood | Possibly visual | Repair scrubber | Damage to sample equipment downstream of scrubber | None |
| | Radioactive particulate not removed from DOG sample | Sample scrubber and/or filter failure | Routine inspection | | HP survey | Repair equipment | Contamination of analyzers | None |
| | Off-gas leak from DOG sample System | Loose fitting, corrosion | Equipment designed for corrosive service | Routine inspection and maintenance | | Repair leak | | None |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Monitoring of DOG (Continued) | Incorrect $H_2$ or $O_2$ analysis | Analyzer malfunction | Approved procedures normally prevent explosion conditions | Two analyzers for each analysis | Disagreement with 2nd analyzer; weekly calibration check | Repair or replace analyzer | $H_2$-$O_2$ explosion | |
| | $O_2$-$H_2$ explosion in sample system | $O_2$ leak into system from piping or equipment failure | Equipment designed for corrosive service | Analyzers have explosion proof cases. No ignition sources in system | | Repair equipment if necessary | Damage to sample system | |
| Monitoring of DOG | Analyzers valved to wrong dissolver | Operator error | Certified operators using approved procedures | No ignition sources in system | Alarm for high $O_2$ | Valve in correct dissolver | None | |
| | Leak in off-gas sample line valves | Valve failure | Valves designed for specific service | Valves easily replaced | Alarm for high $O_2$ | Repair or replace valve | Explosive mixture of $H_2$-$O_2$ in sample system | |
| | Leak in dissolver off-gas line valves | Valve failure | Valves designed for specific service | Valve remotely replaceable | None; need analyzer downstream of individual lines | Repair or replace valve | High $O_2$ in OG line and equipment downstream of individual OG lines | |
| Sampling M and L cell vessels | Restriction in sampler lines | Solids plug | Provisions for clearing plugs with steam and water | | Sampler will not circulate | Water flush or steam | Delay operation | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| Sampling M and L Cell Vessels (Continued) | Damage to sample needle blocks | Operator error | Certified operators using approved procedures | Needle blocks remotely replaceable | Visual | Repair or replace | Delay operation | |
| | Spill sample solution in sampler cell | Operator error | Certified operator | Cell designed for remote cleanup of spills | Visual | Clean up spill | Contamination to sampler cell | |
| | | Equipment failure | Equipment designed for specific service | | Visual | Repair or replace equipment as necessary | | |
| | Damage to cell manipulators | Operator error | Trained operators | Spare parts and manipulators on hand | Visual | Repair or replace | Delay operation | |
| | | Equipment failure | Equipment design | | | | | |
| | Sample solution | Piping failure; corrosion | Piping selected for corrosive services | Cells lined with SST and have sump with jet | Floor sump alarm | Repair leak | Delay operation contaminate cell | |
| Sample transport to analytical facility | Sample carrier stuck in pneumatic tube | Loss of air pressure | Dummy carrier sent first | Backup method for clesring tube | Sample not received in lab. Radiation alarm | Clear tube & shield tube where stuck | Personnel exposure | |
| | | Restriction | | | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Sample transport to analytical facility (Continued) | Sample bottle breaks in carrier | High impact; faulty bottle | Carrier designed to cushion high impact | Bottle sealed in plastic | Visual | Clean up spill; resample | Contamination to sample carrier | |
| | Sample bottle leaks in carrier | Leaky seal | Bottle sealed in plastic | Carrier leak proof | Visual | Clean carrier | Contamination to sample carrier | |
| Glove box operations | Failure of rubber gloves | Puncture or defective glove | Gloves routinely checked | Gloves easily replaceable | Self monitoring or glove monitoring | Replace glove | Personnel hand contamination | |
| | Overexposure from β-γ field | Transfer of highly contaminated material from sampler cell | Monitor material before transfer | Decontamination provisions in sampler cell | Radiation monitor | Shield high radiation objects and decontaminate or remove from glove box | Personnel exposure | |
| | | Repair or servicing of OG equipment | Equipment shielded as necessary | Decontamination provisions | | | | |
| | Escape of airborne contamination to sample corridor | Failure of vent. system to cell and glove box | Glove box designed air tight | Airlock for removing material from glove box | High pressure alarm for cell and glove box; CAM alarm | Restore vent. system | Contaminate sample corridor | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| Normal Operation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence: On This System | Possible Consequences of Abnormal Occurrence: On Related Systems |
|---|---|---|---|---|---|---|---|---|
| X-ray analysis | Exposure of personnel to x-ray beam | Unshielded x-ray beam | X-ray parts normally shielded | X-ray power source has safety circuit interlock | X-ray field monitor alarm | Shield x-ray ports | Overexposure of personnel to x-ray | |
| | Failure of x-ray inst., power supply or computer | Equipment malfunction | Routine inspection and servicing | Other analysis methods are available | Equipment not operating properly | Repair as necessary | Delay operations | |
| | Incorrect analysis by x-ray (Cd) U Zr X-metal | Equipment malfunction | Routine check of system with known standards | Use of other analysis methods for critical samples (Cd) | Routine check or disagreement with other analysis method | Check equipment and repair as necessary | Cd - criticality X-metal - U solids will remain in heel | |
| | | Analyst error in calculating results | Trained analyst | Multiple samples | Disagreement between samples | Reanalyze | U - incomplete U dissolution | |
| | | Analyst error incorrect sample preparation | Trained analyst | | | | | |
| Sample Prep. for X-ray | Spill sample in sample prep. cell | Analyst error | Trained analyst | Cell designed for easy clean-up of spills | Visual | Clean up spill; resample | Contamination to sample prep. cell | |
| | Damage to cell manipulators | Operator error | Trained operator | Spare parts and manipulators on hand | Visual | Repair or replace | Delay analysis | |
| | | Equipment failure | Equipment design | | | | | |

TABLE I (Continued)

POSTULATED ABNORMAL OCCURRENCES FOR (system) (process)

| [illegible]ation | Postulated Abnormal Occurrence | Cause | Primary Safeguard | Secondary Safeguard | Detection | Correction and/or Control | Possible Consequences of Abnormal Occurrence | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | On This System | On Related Systems |
| Sample Prep. for X-ray (Continued) | Loss of sample prep. cell vent system | Equipment failure | Backup blower or jet | Spare parts on hand | High pressure alarm | Restore vent. system | Contaminate lab area if access door was open during failure | |
| Centrifuge solids analysis | Spill solids in hot cell | Operator error | Trained operator | Designed for easy cleanup of spills | Visual | Clean up spill | Contamination in hot cell | |
| | Incorrect analysis of solids by neutron interrogation | Operator error | Trained operator | Check standard before and after sample analysis | Accountability calculations | Recheck sample. Repair equipment if necessary | Loss of uranium. Hold solids until accountability checked | |
| | | Equipment malfunction | Routine check of instrument | | | | | |
| | Failure of analysis system | Equipment failure | Equipment easily removed for repair | Alternate method can be used to sample and analyze | Equipment not working properly | Store solids, repair instrument and analyze later. Use alternate analysis method | None | |

These safety studies have also identified areas of the conceptual process that require additional design features or detail in order to provide adequate safeguards or detection methods. These items are summarized as follows:

(1) Prevent fuel from being inadvertently detached from cranes or handling tools.

(2) Prevent fuel from being lifted beyond safe shielding height in basin.

(3) Provide radiation monitors covering all fuel handling areas.

(4) All cranes must have limit switches and emergency shutdown switches as required for all operations.

(5) Design detailed interlock systems for hot cell slide door.

(6) Protect vulnerable equipment in hot cell from potential accidents during normal operations, maintenance, or decontamination activities.

(7) Prevent fuel from being damaged during transfer from cask to hot cell.

(8) Prevent fuel from being cut in wrong location.

(9) Provide shielded box to transfer contaminated equipment from hot cell to decontamination facility.

(10) Provide fire protection systems as necessary.

(11) Provide sumps with alarms to detect leaks in PM tanks.

(12) Provisions to prevent inadvertent solution transfers to and from PM tanks, dissolvers, and complexing tanks.

(13) Design PM tank samplers to protect personnel from potential accidents.

(14) Provisions to detect failure of closed-loop systems.

(15) Design interlock system and provide field monitors for X-ray analyzer.

(16) Provide constant air monitors and radiation monitors as necessary.

(17) Prevent dilution of soluble poison in chemical makeup solutions.

(18) Design a heating/cooling system for dissolver cones that will not jeopardize criticality safety of the system.

(19) Design dissolver and complexing tank bottoms for criticality safety.

## 5. REFERENCES


1. L. A. Decker, et al, "Classified" Title, ACI-117, February 1972.

2. R. D. Bradley, Preliminary Design Criteria for Proposed Combination Aqueous Project, ACI-168, October 1974.

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