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POTENTIAL SAFETY-RELATED INCIDENTS WITH POSSIBLE APPLICABILITY TO A NUCLEAR FUEL REPROCESSING PLANT

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PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

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ABSTRACT

The occurrence of certain potential events in nuclear fuel reprocessing plants could lead to significant consequences involving risk to operating personnel or to the general public. This document is a compilation of such potential initiating events in nuclear fuel reprocessing plants. Possible general incidents and incidents specific to key operations in fuel reprocessing are considered, including possible causes, consequences, and safety features designed to prevent, detect, or mitigate such incidents.

Key words: nuclear fuel reprocessing
incidents
accidents
risks
safety analyses

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INTRODUCTION

The Savannah River Laboratory (SRL) is developing methodology that can be used to assess the risk of operating a plant to reprocess spent nuclear fuel. This methodology is a modified probabilistic analysis and has been applied successfully to analyses of existing Savannah River Plant (SRP) facilities.

As an early step in the methodology, a preliminary hazards analysis identifies initiating incidents. In the absence of appropriate safety features, these incidents could lead to significant consequences involving risk to onsite personnel or the public. This report is a compilation of potential safety-related incidents that have been identified in studies at SRL and in safety analyses for various commercially designed reprocessing plants.

SUMMARY

A total of over 600 safety-related incidents pertaining to 58 process operations or categories have been identified which, by themselves or in concert with other incidents, may have significant and adverse consequences on the safety of operating personnel and/or the offsite population if appropriate safety features are not provided. Possible causes and potential consequences are identified. Safety features are cited which if incorporated in either the design or operating procedures of a fuel processing facility may serve to prevent the incident, warn of the occurrence of the incident, or mitigate the consequences. This compilation is expected to be useful for design and safety analyses of facilities of this type.

DISCUSSION

Incidents in reprocessing plants differ in several respects from reactor incidents. In nuclear reactors, the dominant incidents can be described by only two conditions, loss of coolant and power increase. In reprocessing plants, however, a very large number of incidents are possible that can result in the loss of small amounts of radioactivity from the facility if features to detect, prevent, or mitigate the incidents are not provided.

Specific differences between the reprocessing and reactor systems are listed below.

- A much larger fraction of incidents in reprocessing plants can be expected to result directly from human error because less automation is used.

- The frequency of incidents resulting in small loss of radioactivity from primary containment for a reprocessing plant can be expected to be greater because of the mobility of the materials and the continual movement of materials between operations.

- The potential energy in reprocessing systems is much less, and significant penetration of protective barriers is more difficult; the frequency of significant penetration per initiating event is therefore less.

- The consequences of reprocessing incidents are lower because the integrity of the barriers can be maintained even under severe conditions.

- The inventory of short-lived isotopes in reprocessing systems is significantly less than in reactor systems.

Identification of potential incident initiators in reprocessing must be based on experience in similar nuclear reprocessing operations, on experience in non-nuclear chemical plants, and on judgment. Such an identification has been made, and the data have been stored in a computer library for convenient retrieval. Principal sources used in the identification of these safety-related incidents were obtained from References 1 to 47.

The incidents in this report are appropriately grouped into General Incidents and Specific Incidents. The General Incidents are generic events that can occur in many of the unit operations and processes; these are grouped according to type, e.g., fires. Since a reprocessing plant operates essentially as a series of diverse and nearly independent operations, Specific Incidents are grouped according to operation, e.g., product evaporation. Some General Incidents are repeated in a few instances in the Specific Incidents section, as appropriate to certain operations. Specific Incidents are cited separately for spent fuel processing and for waste solidification. The detailed format for the incidents includes causes, consequences, and safety features for prevention, detection, and mitigation. Causes are not listed for incidents, such as natural phenomena, that occur externally. Consequences are identified qualitatively, but not quantitatively.

The compilation of potential incidents which follows has been useful at SRL in identifying safety features for inclusion in the design of new facilities and should prove useful elsewhere for both design and safety analyses. The terminology in solvent extraction incidents is consistent with SRL terminology for coprocessing.[47]

1. GENERAL INCIDENTS

1.1 Natural Phenomena

1.1.1 Earthquake Greater than Safe Shutdown Earthquake (Ref. 2,4,5,7,23-27,30,33)

Consequence

- Nil to complete loss of vessel contents

Safety Feature

- All new waste facilities to be designed and constructed to maintain functional integrity in an earthquake producing ground acceleration of 20 percent of the acceleration of gravity (0.2 g) at zero period (corresponds to MM VIII earthquake)

1.1.2 Hurricane (Ref. 2,4,5,22,23,25-27,30)

Consequences

- Breach of containment
- Contamination of environment

Safety Features

- Stack located far enough from important structures to avoid damage to buildings in case of collapse
- Processing area to conform to maximum resistance design criteria
- Holddowns on vulnerable equipment
- Emergency power system protection

1.1.3 Meteorite Impact with One or More Units (Ref. 9)

Consequence

- Release of airborne and liquid-borne radioactivity to environment

Safety Features

- Walls and roof of maximum resistance construction
- Structure designed with a safety factor

1.1.4 Tornado Greater than Design Basis Tornado (Ref. 22, 23,25-27,30)

Safety Features

- Missile protection. All piping shielded to protect against damage from impact.
- Emergency power system protection. Separate maximum resistance construction for emergency power buildings. Oil supply tanks for diesels of maximum resistance construction.

1.1.5 Adverse Winter Operating Conditions (Specific to SRL)

Causes

- Temperature less than 18°F
- Snow
- Ice

Consequences

- Pluggage from liquid freezing in lines
- Broken lines and valves
- Alarm bell clappers frozen
- Reduced maintenance

Safety Features

- Steam tracing or insulation on liquid-bearing lines exposed to weather
- Safety factor on tank roof loading
- Effective drying in instrument air system
- Protection of evaporation instrumentation and steam control systems

1.1.6 Flooding from River (Specific to SRP)

Cause

- Failure of highest of a series of upstream dams, with subsequent overtopping of all downstream dams

Consequence

- Flooding

Safety Feature

- Site selection

1.1.7 Adverse Effects of Lightning

Consequences

- Interruption of electric power
- Limitations to outside work
- Fire
- Instrument and equipment damage

Safety Features

- Lightning protection in electrical supply circuitry
- Emergency diesel generator for critical equipment
- Lightning rods on high equipment

1.2 Contamination

1.2.1 Personnel Contamination

Causes

- Inadequate protective clothing
- Procedural violation
- Airborne activity
- Failure of a containment barrier

Safety Features

- Procedures, monitoring, and training
- No expansion joints in process cells
- Control of personnel access to process area
- Piping designed to minimize backup of radioactive material through pneumatic lines or samplers
- Instrument design. Pneumatic-electrical interface to protect personnel against suckback and eructation radiation effects.
- Ventilation. Process areas sealed by sufficiently high inward flow of air across openings to prevent escape of airborne radioactivity.

- Portable and permanently installed radiation and air monitors and alarms are provided in areas requiring personnel access. Monitors and alarms are on emergency power.

1.2.2 Unexpected General Contamination (Ref. 5)

Causes

- Leaks, spills, and tools
- Fire
- Failure of a containment barrier
- Procedural violation
- Uncontrolled reaction
- External causes

Consequence

- Increased activity to cell ventilation system

Safety Features

- Stainless steel flooring for process cells
- Sumps and sump transfer piping
- Primary confinement of process solutions and associated radionuclides is provided by vessels and piping. Cells provide secondary confinement. Airborne particulates, aerosols, or vaporized process materials go to the process building ventilation system for filtration.
- Service piping sloped toward working cells
- Cold side of piping system above the highest point of the hot side. Positive pressure on cold side when open to the hot side. Steam lines purged with air after steam is cut off. Seal pot on evaporators.
- Inward flow of air across openings
- Streams from shielded areas monitored for gamma activity
- Constant air monitors, remote radiation detectors with alarms and readout in control room
- Gamma monitors on process stacks
- Fire protection

1.2.3 Airborne Activity

Causes

- Explosion
- Eructation
- Overpressurization (fume-out)
- Failure of a containment barrier (rupture, spill, leak)
- Boilover
- Overflow
- Fire
- Air reversal
- Low off-gas header vacuum
- Dust collector failure
- Pluggage in powder handling or off-gas system
- Maintenance or repair work
- Suckback through instrument or sample lines
- Power failure

Consequences

- Excessive activity to ventilation system
- Inhalation uptakes by workers
- Personnel contamination

Safety Features

- Air monitors and alarms in areas requiring access by personnel
- Ventilation system provides high inward flow of air across openings
- Air flow is from area of low contamination to area of high contamination
- Discharge of air through filters
- Ventilation system in control center separate from rest of system
- Administrative control, training, procedures
- Temperature and pressure instruments, alarms
- Access control of personnel

- Dust control and containment. Sorbent materials are handled in isolated systems to preclude release of particles.
- Emergency power system with automatic startup
- Backup blowers start automatically
- Instrument interfacing
- Vessel ventilation avoids pressurization, suckback, and siphoning

1.3 Externally Induced

1.3.1 Large Aircraft Impact (Ref. 5,23)

Cause

- Human error or aircraft malfunction

Consequences

- Impact damages coolant system
- Fire causes volatilization of fuel
- Release of airborne and liquid-borne radioactivity

Safety Features

- Plant located sufficiently far from airport that potential crashes are only slightly related to airport operations
- Walls and roof of maximum resistance construction
- Emergency power system protection

1.3.2 Vessel Rupture from Impact of Carried or Dropped Equipment

Causes

- Crane failure
- Human error
- Procedural violation

Consequences

- Solution released to cell floor and sump
- Airborne activity to cell ventilation system

Safety Features

- Piping shielded to protect against damage from impact
- Secondary confinement provided by cell
- Air activity monitors
- Iodine absorbers for cell air to cope with process containment failure on demand
- Impact resistant construction
- Administrative control

1.4 Fires

1.4.1 General Fire

Causes

- Vehicle fuel system
- Welding

Consequences

- Equipment damage
- Airborne activity
- Loss of process control
- Filter pluggage

Safety Features

- Ionization-type smoke detectors and continuous sampling of ventilation air
- Fire extinguishers (water, Halon, CO_2)
- Capability of controlling fire water to specific parts of facility, to avoid contamination spread
- Water supply
- Safety-related functions not impaired by fire
- Alarms audible throughout facility
- Monitoring systems, alarms, and suppression systems compatible with chemical and radiation environment
- Fire walls
- Flame arrestors in off-gas lines to protect against flashback of hydrogen
- Visual observation, i.e., shielded viewing windows

1.4.2 Filter Fire in Vessel Vent Lines

Causes

- Organics enter the waste tank, vaporize, and leave with tank off-gas
- Spark ignition

Consequences

- Increased activity to off-gas system

Safety Features

- Decanters upstream of evaporators removing floating organic material
- Off-gas condensers and knock-out pots
- Preheaters prevent condensation of organics on filter
- Redundant, continuous monitor with alarm
- Separation of series filter units to preclude common cause failures
- Ionization-type smoke detectors continuously monitor ventilation air
- Sand filter downstream of HEPA filter*
- Flame-resistant materials

1.4.3 Fire in Stack (Ref. 10)

Causes

- Hydrogen from radiolysis of process solution
- Ignition by lightning or static electricity

Consequences

- Damage to HEPA filters

Safety Features

- Flame arrestors
- Stack thermocouples
- Equipment purges. Protection against condensate freezing in off-gas lines external to buildings.
- Dampers

* High-efficiency particulate air filter

1.4.4 Fire in a Process Cell (Ref. 14)

Causes

- Flammables present in cell
- Ignition source
- Spontaneous combustion

Consequences

- Interruption of the general ventilation for alpha monitoring of the stack; for 5 x 10^{-6} curies per cubic meters stack activity the system activates total closing of the ventilation system with consequent loss of dynamic containment of the building.
- All filters may be lost

Safety Features

- Fire suppression system
- Manual backup to automatic system
- Fire detectors and alarms compatible with radiation, chemical, and temperature environment
- Automatic signal to control room and opening of the outlet ventilation duct in the cell
- Activity monitor (audible and visual)
- Multiple containment barriers and fire walls
- Visual observation through shielded windows, in-cell TV

1.4.5 Fire Suppression System Failure (Ref. 14)

Causes

- No electric power or instrument air
- Valves fail closed
- Broken feed pipe
- Alarm failure

Consequences

- Fire continues to burn with release to ventilation system
- Filter pluggage

Safety Features

- Manual activation of system if automatic suppression system fails
- Alarms
- Emergency air reservoir on suppressant discharge valve

1.4.6 Electrical Fire

Causes

- Short circuit
- Overload

Consequence

- Loss of instruments and process control

Safety Features

- Circuit breakers
- Smoke detectors and heat sensors
- Fire extinguishers and alarms

1.5 Uncontrolled Reactions

1.5.1 Evaporator Boilover

Causes

- Excessive heatup rate
- Loss of temperature control
- Overfilling
- Entrained solvent in feed

Consequence

- Release of radioactive material from primary containment

Safety Features

- Sump
- Secondary confinement
- Temperature - steam interlock (where TBP* or uranyl nitrate are present, temperature limited to 135°C or less)

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* Tributyl phosphate

- Liquid level controls and alarms
- Shielding against beta, gamma, and neutron radiation
- Remotely located radioactivity monitors with control room readout
- Visual observation
- Decantation of floating material
- Emergency water for cooling and dilution
- Acidification (to decompose any azides that may be present)
- Pressure relief on the steam supply

1.5.2 Red-Oil Explosion in an Evaporator (Ref. 44)

Causes

- Reaction between TBP (solvent) and uranyl nitrate
- Solvent (TBP + kerosene) in feed
- Temperature greater than 130°C

Consequences

- Damage to equipment
- Release of radioactive material to cell
- Airborne activity
- Radioactive material in service and sample lines

Safety Features

- Sumps
- Secondary confinement
- Service line design (e.g. pneumatic-electrical instrument interface to protect personnel against suckback and eructation)
- Pressure relief on steam suppy and seal pot to protect evaporator from overpressurization
- Air monitors
- Temperature and steam pressure control
- Decanters with inlet baffles to maintain smooth blending of incoming solution with stored solution to avoid re-entrainment of organic layers
- Agitators

1.5.3 Eructation in Evaporator, Dissolver, or Acid Recovery Unit

Causes

- Foreign material in feed
- Excessive heatup rate
- Loss of temperature or pressure control

Consequences

- Release of radioactive material to cell and to ventilation system
- Radioactive material in service and sample lines

Safety Features

- Sumps
- Secondary confinement
- Shielding against beta, gamma, and neutron radiation
- Remotely located radiation detectors with control room readout
- Acidification to decompose any azides present
- Service and sample line design to reduce backup of radioactive material through piping such as pneumatic lines or samplers
- Air monitors such as in-cell monitors to detect volatile releases
- Temperature and steam pressure control
- Decanters
- Agitators to homogenize solutions and prevent accumulation or organic material

1.5.4 Explosion in Vessel Vent System

Cause

- Ammonium nitrate collects on filters

Consequences

- Equipment damage
- Airborne release to off-gas treatment system
- Pressure reversal

Safety Features

- Backup off-gas blowers start automatically if primary unit fails
- Vessel vent system alarms signal pressure reversals
- Differential pressure monitor and alarm on off-gas filters
- Humidity control
- Backflow dampers prevent flow reversals
- Vessel vent header sloped and drained to a special tank to prevent entrainment and transfer of solutions to the caustic scrubbers
- Redundant filters

1.5.5 Calciner Eructation

Causes

- Uncontrolled reaction
- Excessive heatup rate
- Loss of temperature or pressure control
- Pluggage in off-gas system

Consequences

- Fire
- Explosion
- Radioactive material released to cell
- Radioactive material released to ventilation system

Safety Features

- Sumps
- Secondary confinement
- Air monitors
- Pressure relief valves on steam supply and rupture discs on process equipment
- Process temperature and pressure indicators interlocked with steam supply controls
- Cleanup capability in cell
- Alarms and relief valves

- Dust collection system with dual filters and air capacity monitors

1.6 Leaks

1.6.1 Leak in Pool Water Treatment System

Causes

- Gasket failure
- Valve failure

Consequence

- Pool water leaks to building environs

Safety Features

- Water is channeled to sumps by leak collection system, then returned to pool via filter-deionizer system
- Leak is isolated and repaired
- Spill area decontaminated

1.6.2 Leakage of Primary Coolant into Secondary System (Ref. 2)

Causes

- Hole in heat exchanger
- Corrosion, erosion
- Weld failure

Consequence

- Contamination of secondary coolant and cooling towers

Safety Features

- High pressure on secondary coolant side of equipment
- Continuous (no welds) coils
- Corrosion allowance in design. Vessels are corrosion-tested and all welds are inspected
- Monitors on secondary cooling water to detect activity
- Diversion of condensate and cooling water in the event of a tube failure

- Evaporators are water-cooled when high activity material is in the evaporator but is not being evaporated

1.6.3 Coil Failure

Causes

- Weld failure
- Corrosion
- Improper construction materials
- Vibration

Consequence

- Activity enters stream condensate return or cooling water system

Safety Features

- Closed loop systems supply steam and cooling water
- Coil pressurization. Steam and cooling water pressures are higher than pressure inside process vessel
- Continuous (no welds) coils
- Corrosion allowance in design
- Secondary condensate and cooling water continuously monitored for activity
- Diversion to a basin if radioactivity found in returned condensate or cooling water
- Evaporators reboilers are water-cooled when high activity material is in the evaporator but is not being evaporated

1.6.4 Tank or Vessel Leak (Ref. 42)

Causes

- Corrosion
- Improper installation or replacement
- Valve failure
- Gasket or flange failure

Consequences

- Release to cell floor
- Contamination of cell filters
- Fissile material

Safety Features

- Beta, gamma, and neutron shielding. Most maintenance done by remote operation.
- Secondary confinement is provided by cells. Liquids flow to collection sumps. Airborne activity (particulates, aerosols, or vaporized process materials) is filtered.
- Transfer of fissile material from safe to unsafe geometry must not be possible as the result of a single failure, such as a leak
- Sump system and liquid level monitors with alarms on sumps
- Sump jets (or pumps) feed a geometrically-safe collection tank
- Corrosion allowance in design
- Radiation monitors with remote detectors and alarms and readout in control room
- Visual observation through shielded windows
- Stainless steel flooring where contaminated liquids can contact cell floor

1.7 Electrical Failures

1.7.1 Fire in Emergency Power System (Ref. 5)

Causes

- Electrical fire
- Spilled diesel oil ignites
- Fuel oil tank fire
- Overheated lubricant

Consequence

- System not available

Safety Features

- Preventive maintenance
- Combustible gas monitor in fuel storage area
- Ignition sources eliminated from fuel storage area
- Remote fuel storage area diked to contain leaked oil
- Fire detectors in fuel storage area, in generator area, and on control panels
- Smoke detectors on ventilation systems
- Fire alarms audible throughout facility
- Fire indicator on control panel
- Fire suppression systems for storage area, generator area, control room
- Manual fire suppression system activation, if automatic operation fails

1.7.2 Loss of Normal Electric Power

Causes

- Power to substation interrupted
- Substation failure
- Failure in motor control center
- Natural phenomena

Consequences

- Loss of process control
- Loss of ventilation (air reversal)
- Potential release of radioactivity only in the event of redundant system failure

Safety Features

- Diesel-powered emergency generator housed in building of maximum resistance construction
- Diesel generator starts automatically
- Emergency power to blowers, instruments, alarms, scrubber pumps, coolant pumps, emergency lighting, fire suppression system
- Control valves for on-off services are instrument air operated from solenoid valves. Valves fail in safe position.

- Dual normal-power supplies, i.e., two uninterruptable instrument power supplies, two main transformers, and double-ended feeder supply loop
- Backflow dampers on ventilation system
- Auto-restart equipment

1.7.3 Failure of Emergency Power System

Causes

- Diesel fails to start or fails to run
- General malfunction
- Switchgear failure
- System under repair
- System turned off (operating error)

Consequences (if normal electric power fails)

- Loss of process control (instruments, cooling)
- Loss of ventilation (air reversal)
- Potential release of radioactivity only in the event of redundant system failure

Safety Features

- Dual diesel-powered generators
- Emergency-power-system-operating indicator in control room
- Uninterruptible (battery-powered) power supplies
- Ventilation dampers close automatically
- Manual switchgear operation, if autoswitching fails

1.8 Ventilation Problems

1.8.1 Failure of Exhaust or Supply Motor

Cause

- Electrical failure (e.g., shorted to ground)

Consequence

- Reduced flow of air through facility

Safety Features

- Backup system automatically brought online
- Vacuum instruments on ventilation header

1.8.2 Air Reversal (Ref. 1,7)

Causes

- Supply fan and damper failure
- Filter clogging combined with failure to stop air supply blowers
- Exhauster failure

Consequence

- Airborne contamination in facility

Safety Features

- Backup fans and blowers
- Interlocks
- Automatic isolation dampers
- Backflow dampers prevent flow reversals
- Separate ventilation system in control center
- Backup systems consisting of iodine absorbers for cell air to cope with process containment failure on demand
- Instrumentation
- Vessel vent system alarms signal pressure reversals
- Roughing filter on inlet air

1.8.3 HEPA Filter Failure (Ref. 7)

Causes

- Filter plugged by smoke (fire)
- Filter waterlogged
- Mechanically fails dry
- Housing fails
- Installed incorrectly (DOP* test fails)
- Differential pressure warning fails
- Personnel response lacking
- Vibration

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* Dioctylphthalate

Consequence

- Potential release to stack

Safety Features

- Moisture control is achieved by temperature control that maintains off-gas temperature above dew point to prevent condensation on filters
- Fire resistant materials
- Standby HEPA
- Sand filter
- Differential pressure monitor and alarm on off-gas filters
- DOP tests
- Inspection

1.8.4 Process Vessel Pressurization (Ref. 1,2,5,42)

Causes

- Pluggage of off-gas eductor or filter
- Failure of feed-gas or off-gas control valves
- Loss of normal cooling water to vessel coils or condenser
- Exhauster failure

Consequences

- Flow reversal
- Discharge of off-gas to cell ventilation
- Dissolver solution to cell sump

Safety Features

- Automatic activation of emergency cooling water
- Backup cooling pumps
- Pressure instrumentation and off-gas temperature instrumentation interlocked with operation
- Pressure relief valves and rupture discs
- Vent header vacuum instruments and alarms
- Filter pressure-drop monitors and alarms
- Filter blowback with regulated air pressure employed to clean metal filters

- Backup exhausters
- Cell ventilation system is routed to process building where airborne particulates, aerosols, or vaporized process materials are filtered
- In-cell monitors to detect volatile releases
- Standby HEPA for cell air
- Standby iodine absorbers for cell air to cope with process containment failure on demand

1.8.5 Radioactive Contamination in Clean Area

Causes

- Air flow reversal from contaminated area
- Ventilation system failure

Consequences

- Skin contamination by operating personnel
- Inhalation uptakes by operating personnel
- Potential release of airborne activity through the building ventilation system

Safety Features

- Backflow dampers prevent flow reversals
- Ventilation system is once-through with controlled building inleakage
- Flow of air from areas of low contamination to areas of high contamination
- Ventilation in control center separate from rest of system
- Process areas have sufficiently high inward flow of air across any opening to prevent escape of airborne radioactive materials
- Radiation monitors, air monitors, and alarms in all personnel access areas
- Storm sewer is monitored continuously for radioactive material. Flow is diverted to a retention basin in the event of contamination.
- Dust control containment. Mechanical conveyors sealed for containment during transfer.
- Emergency power to ventilation fans

- Administrative control
- Service piping sloped toward working cells

1.9 Off-Gas Treatment Malfunctions

1.9.1 Failure of Exhaust Blower

Causes

- Power failure
- Motor failure
- Damper malfunction

Consequence

- Radiological consequences only for multiple simultaneous failure of several safety backup systems

Safety Features

- Spare exhaust blower with automatic start
- Backflow dampers close automatically on shutdown of a blower
- Pressure control system
- Differential pressure monitor and alarm on off-gas filters
- Pressure/vacuum devices to vent primary to secondary
- Differential pressures between the atmosphere, the process area, and the control room indicated on two (2) photohelic gages in the control room

1.9.2 Airborne Activity Release from Scrubber (Ref. 10)

Causes

- Inadequate solution in scrubber
- Scrubber solution composition incorrect
- Scrubber overloaded
- Aerosol release from scrubber

Consequence

- Abnormal release to HEPA and sand filter

Safety Features

- Scrubber has high and low alarms for liquid level and pH
- Backup scrubber solution pumps
- Scrubbers have mist eliminators on the vapor discharge line
- Scrubber solution specific gravity monitor

1.9.3 Capacity of Off-Gas System Overloaded

Causes

- Pressurization
- Overheating
- Rapid reaction rates in process vessels
- Uncontrolled reactions

Consequences

- Airborne release to stack
- Filter pluggage
- Filter failure

Safety Features

- Final treatment of off-gas by HEPA filter, sand filter, and process stack
- Off-gas flow monitors
- Header instrumentation and alarms
- Iodine monitor on off-gas system
- Differential pressure monitor and alarms on off-gas filters
- Off-gas scrubbers discharge solutions to a slab-shaped settling tank. Recycled solution is pumped through a heat exchanger with sensors for water temperature and flow. Waste scrubber solutions are pumped to a check tank with a sampler and instruments for liquid level, specific gravitiy, and temperature.
- Condensers have overhead gamma monitors
- Absorber beds in series with activity monitors

1.9.4 Ruthenium Escapes to Off-Gas System

Cause

- Formation of volatile ruthenium compounds

Consequence

- Release of radioactive material

Safety Features

- Scrubbers for ruthenium removal
- Chemical additives, such as sugar, to suppress the volatility of ruthenium
- Gamma monitors and thermocouples on process stacks
- On-line monitoring
- All condensers have overhead gamma monitors
- Condenser alpha monitors
- Dual absorber beds in series with activity monitors, between and downstream

1.9.5 Dissolver Pot or Evaporator Coils not Submerged During Shutdown

Causes

- Operator error
- Procedural difficulty

Consequence

- High loss of volatiles to cell atmosphere

Safety Features

- Iodine monitor on off-gas system
- Process stacks equipped with gamma monitors and thermocouples
- Final treatment of off-gas by HEPA filter, sand filter, and process stack
- Evaporator solutions monitored for temperature and specific gravity
- Evaporators reboilers are water-cooled when high activity material is in the evaporator but is not being evaporated
- All condensers have overhead gamma monitors
- Absorber beds

1.10 Process Upsets

1.10.1 Charge of 90-Day Cooled Fuel (Ref. 5)

Causes

- Incorrect fuel assembly identification
- Erroneous instructions
- Procedural violation

Consequence

- Release to stack of radioiodine

Safety Features

- Gamma monitors have remote radiation detector heads with alarms and readout in control room
- Iodine monitors in DOG* system
- Iodine removal system
- Dual absorber beds in series with activity monitors, between and downstream
- Certified records on incoming fuel
- Training, administrative control
- Lighting adequate for color identification

1.10.2 Blockage of Normal Flow Lines (Ref. 1)

Causes

- Pluggage
- Freezing
- Valving error
- Failure of flow controller

Consequences

- Increased criticality potential
- Loss of material from overflow

Safety Features

- Liquid level indicators with high-level and low-level alarms
- Protection against condensate freezing in off-gas lines external to building

*Dissolver off-gas

- Valve labelling
- Process jets are controlled by gang valve assemblies. A programmer ensures a correct sequence of valve operation.
- Solenoid valves
- Flow monitors

1.10.3 Overflow

Causes

- Failure of air lift and level controller
- Personnel difficulties
- Valving difficulties
- Instrument difficulties
- Alarm difficulties
- Process difficulties
- Procedural difficulties
- Pump difficulties
- Piping errors
- Equipment failure

Consequence

- Solution to cell sump

Safety Features

- High level alarm. Liquid level indicators with high-level and low-level alarms.
- Automatic diversion of waste in receipt tank if the liquid level reaches a specified level
- Pump cutoff switch
- Heavy beta-gamma shielding, neutron shielding, and contamination control. Most maintenance and process control are by remote control. Decontamination necessary before hands-on maintenance.
- Gamma monitors
- Visual observation through shielded windows and in-cell TV and optical systems

- Ventilation system removes airborne particulates, aerosols, or vaporized process materials
- Sump system contains fixed poisons for criticality control

1.10.4 Transfer Error

Causes

- Valving error
- Personnel difficulties
- Piping error
- Equipment failure
- Procedural difficulties

Consequence

- Transfer of solution to other vessels or to cell sump

Safety Features

- Valve labeling
- Gang valve assemblies control process jets. A programmer ensures the correct sequence of valve operations.
- Liquid level indicators with high-level and low-level alarms
- Fixed poisons in sump receipt tanks. Sumps have liquid level monitors with alarms. Sump jets (or pumps) feed a geometrically-safe collection tank with a decanter and a sampler.
- Shielding
- All vessels, lines, equipment, and sumps that could conceivably receive fissile material in quantities exceeding the concentration limit, have geometrically-favorable design
- Motor load currents are monitored to show that equipment (pumps, agitators, and mixers) are drawing the correct amperage
- Blanks
- Dedicated piping

1.10.5 Suckback

Cause

- Pressurization or steam condensation

Consequence

- High radiation levels in areas occasionally occupied by personnel

Safety Features

- Vent header maintains vessels under a slight vacuum
- Noncondensible vapors are sent to the vessel off-gas system (VOG) through a condenser vent header
- Seal pots
- Pneumatic-electrical instrument interface to protect personnel against suckback

1.10.6 Siphoning

Cause

- Design error

Consequence

- Transfer of vessel contents to another vessel or to the cell sumps

Safety Features

- Seal pots protect evaporator from overpressurization and from pressure surges that could force radioactive material through instrument and service lines
- Vessel ventilation system avoids siphoning
- Liquid level indicators with high-level and low-level alarms

1.10.7 Loss of Cooling

Causes

- Cooling towers inoperative
- Cooling pump failure

Consequence

- Loss of cooling water supply

Safety Features

- Cooling water for heat exchanger is supplied by emergency cooling pond
- Temperature of water in pond will rise until rate of evaporation is sufficient to remove decay heat
- Backup cooling water pumps start automatically
- Cooling water pumps are on emergency electrical power system
- Ventilating air diverted to filter system if required
- Temperature monitor on gas discharge

1.10.8 Incorrect Material Transfer (Feed Chemicals, Product Materials, or Incorrect Materials)

Causes

- Procedural errors
- Operation errors
- Piping errors
- Valving errors

Consequences

- Release of radioactive materials
- Process disruption

Safety Features

- Procedural control (limits on mass and concentration)
- Current monitors on motors show that equipment (pumps, agitators, and mixers) is drawing the correct amperage
- Specific gravities of cold feed streams are monitored continuously
- Sampling capability for online and offline analysis is required on all major product and waste streams
- Neutron monitors
- At least two operating criticality monitors

- Dedicated piping
- Blanks on flush lines and chemical addition lines preclude inadvertent addition of precipitant
- Valve labeling
- Gang valves control process jets. A programmer ensures a correct sequence of valve operation.

1.10.9 Suckback into Gang Valve

Cause

- Steam pressure loss during operation of a transfer jet

Consequences

- Additional activity to off-gas treatment facility
- Radiation exposure of personnel

Safety Features

- Radiation and air monitors and alarms are provided in areas requiring access by personnel
- Bypass from the air header to the process side of the gang valve
- Automatic air blow of the gang valves
- Pressure switch on steam valve

1.10.10 Instrument Failure

Causes

- Electrical fire
- Loss of instrument air
- Power failure
- Short circuits
- Mechanical failure
- Corrosion
- Pluggage

Consequences

- Potential loss of process control, e.g., overheating
- Failure to detect process malfunctions, e.g., overflow

Safety Features

- Regular testing and calibration
- Redundant instruments for critical parameters
- Emergency power system
- Test capability during operation
- Protection systems designed to fail into a safe mode
- Multiple-parameter monitoring

1.10.11 Loss of Instrument Air

Causes

- Compressor failure, electrical or mechanical
- Water in lines, air dryer failure
- Pluggage

Consequences

- Instrument failure
- Loss of process control

Safety Features

- Instrument air pressure monitor
- Air pressure reservoir for short-term supply
- Control systems designed to fail into a safe mode

2. SPECIFIC INCIDENTS FOR FUEL PROCESSING

2.1 Fuel Receiving and Storage

2.1.1 Leakage of Coolant from Irradiated Fuel Cask (Ref. 4,6)

Causes

- Cask damaged in transit
- Valve failure

Consequences

- General vehicle, cask, and area contamination
- Potential for fire, if coolant is flammable or sodium
- Coolant overheated due to loss of coolant

Safety Features

- Survey upon arrival
- Coolant temperature instrumentation on cask
- Coolant cleanup capability

2.1.2 Fuel Damage in Transit or upon Arrival (Ref. 6,7,9)

Causes

- Collision accident
- Cask dropped

Consequences

- Release of krypton-85 and other radioactive gases during fuel unloading
- Contamination of fuel unloading area

Safety Features

- Cask coolant monitor
- Cask vapor monitor
- Unloading area ventilation system
- Canning for leaking fuel
- Decontamination capability in fuel unloading area

2.1.3 Vehicle Fire

Causes

- Fuel system malfunction
- Welding (repair) operations
- Short circuit
- Defective truck exhaust

Consequences

- Equipment damage
- Building functions impaired
- Vehicle and possible structural damage
- Cask coolant overheated

Safety Features

- Smoke detectors
- Fire suppression system in receiving and holding area and in welding area

2.1.4 Fuel Cooling Time Too Short (Ref. 1,4)

Cause

- Shipper's error

Consequences

- Reduced shielding efficiency
- Abnormally high radiation outside cask
- Cask coolant and fuel overheated

Safety Features

- Cask temperature and pressure instruments
- Survey upon arrival for radiation and coolant temperature
- Green fuel storage area

2.1.5 Cask Inadvertently Vented

Causes

- Valve failure
- Erroneous instructions/procedural difficulty

- Unexpected area contamination
- Airborne activity released from cask

Safety Features

- Ventilation system
- Activity monitor and alarms
- Carbon filters remove iodine

2.1.6 Secondary Cask Coolant Contaminated (Ref. 1,4)

Cause

- Leak of primary coolant or improper monitoring before shipping

Consequences

- Contamination of unloading area

Safety Feature

- Sampling and cleanup in cask washdown and cooling area

2.1.7 Cask Dropped (Ref. 1,2,5,9)

Causes

- Cask damaged in transit
- Equipment failure or operating error (e.g., release accidentally tripped)
- Crane overloaded

Consequences

- Contaminated water splashed, personnel injury, fuel assembly damage
- Cask venting

Safety Features

- Cask cannot be moved over storage pool
- Area ventilation system

2.1.8 High Temperature in Primary Cask Coolant (Ref. 4,5,7,9)

Causes

- Fuel cooling time too short
- Fouling of cask heat transfer surfaces
- Failure of secondary heat transfer system

Consequences

- Cask pressurized
- Rupture of cladding

Safety Features

- Monitoring of cask coolant temperature

2.1.9 Cask Pressurization (Ref. 2)

Causes

- Loss of coolant
- High temperature in cask

Consequences

- Airborne activity released on venting, area contamination

Safety Features

- Pressure check and venting

2.1.10 Water Pumped into Sodium Storage Tank

Causes

- Operator error/wrong procedure followed
- Wrong cask mated to cask unloading port

Consequences

- Violent water-sodium explosion
- Explosion/fire
- Hydrogen release to off-gas system

Safety Features

- Procedural control
- Incompatible fittings on different systems

2.1.11 Hydrogen Explosion in Fuel Cleaning Vessel

Causes

- Uncontrolled sodium reaction in fuel cleaning vessel, overloaded catalytic oxidizer, ignition of hydrogen in off-gas
- Loss of inert cell atmosphere (humidity control) during unloading of sodium cooled fuel, uncontrolled water-sodium reaction in cell, ignition of hydrogen in cell

Consequences

- Damaged cell equipment
- Damaged off-gas system
- Release of airborne activity from process cell

Safety Features

- Catalytic recombiner for hydrogen
- Flame arrestors on off-gas outlets of catalytic oxidizer and fuel cleaning unit
- Hydrogen and humidity monitors in the cell
- Pressure monitors and pressure-relief system
- Cell ventilation system

2.1.12 Loss of Cooling (Ref. 5)

Causes

- Loss of normal and emergency cooling water systems
- Large basin leaks (e.g. earthquake caused)

Consequences

- Loss of water from storage pool
- Pool water boiloff
- Fuel overheating

Safety Features

- Maximum resistance construction for transfer lines, pumps, heat exchangers, and control systems
- Redundant pumps and lines for makeup-water systems
- Redundant cooling loops

- Maximum resistance construction for basin
- Instrumentation (cooling-water flow and pressure, pool water temperature, and basin leak detectors)
- Short-term evaporative cooling of the fuel
- Poisoned storage racks and hardware for criticality mitigation
- Gravity-flow poison tank

2.1.13 Criticality

Causes

- Distortion of fuel-storage array by earthquake or impact of heavy equipment, aircraft, crane, etc.
- Improper storage of fuel due to faulty identification, lack of identification, incorrect assay, or violation of procedures
- Fuel assembly dropped into fuel storage array
- Fissile material on pool water filter

Consequences

- High radiation exposures and possibly fatalities
- Radioactivity offsite

Safety Features

- Maximum resistance construction
- Racks designed to maintain safe spacing under impact
- Limits to travel of crane over pool
- Computerized fuel identification system
- Nondestructive assay of fuel before storage
- Poisons in racks and storage hardware
- At least two operating criticality monitors with uninterruptable power supplies
- Fuel inventory audits
- Gravity flow poison tank
- Ventilation system capable of handling airborne fission products in the event of criticality

2.1.14 Sodium Fire

Causes

- Sodium coolant leaking from cask, not detected before cask washdown
- Spill of sodium coolant during transfer from cask and loss of inert atmosphere
- Sodium leak from transfer line or storage tank and loss of cell inert atmosphere

Consequences

- Damage to equipment
- Sodium smoke release to cell ventilation system
- Temperature as high as 1250°F

Safety Features

- Restoration of inert atmosphere by auxiliary suppression system or backup inert atmosphere system
- Fire walls
- Sodium cleanup capability

2.1.15 Damage to Fuel Assembly Outside Cask (Ref. 2,5,7,9)

Cause

- Assembly dropped, mechanical failure of crane components or lifting accessories, release accidentally tripped

Consequence

- Fuel cladding damaged, contamination released

Safety Feature

- Failed fuel canning prior to storage

2.1.16 Shipping Errors Detected at Unloading

Causes

- Inability to identify fuel
- Inadequately marked fuel
- Discrepancies between contents and manifest

Consequence

- Potential criticality

Safety Feature

- Isolation area for suspect fuels

2.1.17 Surface Contamination not Removed from Cask (Ref. 4)

Cause

- Procedural violation, and monitoring equipment failure

Consequence

- Minor cask pool contamination

Safety Features

- Cask cooling and washdown system
- Cask pool water decontamination capability

2.1.18 Damage to Stored Fuel (Ref. 1,7)

Causes

- Fuel dropped or knocked over
- Equipment dropped into storage pool

Consequence

- Pool water contamination

Safety Feature

- Pool water cleanup system

2.1.19 Fuel Element Raised Above Safe Shielding Level of Water

Cause

- Failure of stops of fuel handling equipment, operator error in manual handling

Consequence

- High radiation exposure at pool surface

Safety Feature

- Fuel handling stops

2.1.20 Low Water Level (Ref. 7,9)

Causes

- Accidental pumping out of incorrect pool section
- Loss of cooling with subsequent boiloff
- Earthquake greater than design basis
- Tornado greater than design basis
- Aircraft crash
- Liner leak

Consequence

- High radiation at pool surface, fuel overheating

Safety Feature

- Redundant and emergency water makeup. Leak detection and automatic pumpout, radiation alarms

2.1.21 Rupture of Fuel During Storage (Ref. 5,9)

Causes

- Corrosion
- Equipment other than cask or basket dropped
- Earthquake greater than design basis
- Aircraft crash
- Tornado greater than design basis
- Meteorite

Consequence

- Increased pool water activity

Safety Feature

- Portable vent hood for ruptured fuel cans

2.1.22 Loss of Cooling Capability (Ref. 2,5,7)

Causes

- Loss of supply system
- Loss of primary loop cooling
- Loss of primary and emergency power

Consequence

- Pool boiloff and fuel overheating

Safety Features

- Redundant pumps and emergency pond

2.1.23 Storage Container Floats to the Surface

Cause

- Radiolytic gas formation in sealed can

Consequence

- High radiation levels near pool

Safety Features

- Remote operation
- Fuel canisters weighted down or vented

2.1.24 Wrong Fuel Transferred to Mechanical Cell (Ref. 1)

Causes

- Procedure violated
- Fuel identification problem

Consequence

- Abnormal release of fission products to off-gas system

Safety Features

- Fuel monitor (gamma)
- Computer inventory control and crane indexing
- Off-gas system
- Fuel return capability

2.1.25 Cooling Towers Become Inoperative

Cause

- Natural phenomena

Consequence

- Loss of cooling water supply

Safety Feature

- Cooling water for heat exchanger is supplied by emergency cooling pond

2.1.26 Loss of Normal Cooling Water

Causes

- Cooling tower inoperative
- Loss of pumps from loss of normal electrical power
- Pump failure

Consequences

- Pool water temperature increase
- Low pool water level

Safety Features

- Emergency cooling water pond and redundant pumps
- Emergency diesel generator automatically starts

2.2 Shearing

2.2.1 Pyrophoric Fire

Causes

- Small particle size
- High surface/volume
- High surface/mass
- Roughened zirconium surface
- Moisture (3 to 25%)
- Oxidizing environment
- Combustible materials

- Mechanical agitation
- Accumulation of metals
- Zirconium aerosols
- Ignition source

Consequence

- Dispersal of radioactivity

Safety Features

- Argon eductors
- Argon purging and cooling
- Administrative control of fines
- Detectors and extinguishers

2.2.2 Fuel Jammed or Stranded in Shear

Cause

- Shear failure

Consequence

- Excessive radiation for maintenance. Possible overheating of fuel

Safety Features

- Provisions for remote retrieval of fuel
- Emergency argon cooling

2.2.3 Malfunction of Inert Gas System (Ref. 4,5)

Causes

- Controller failure, loss of supply
- Operating error

Consequence

- Increased potential for a zirconium fire

Safety Feature

- Flow instrumentation and operator control

2.2.4 Pressurization of Shear (Ref. 5)

Cause

- Off-gas flow restriction, excessive inert gas flow and low-vent header vacuum

Consequence

- Release of radioaerosol to cell atmosphere

Safety Feature

- Pressure instrumentation and operator control

2.2.5 Release of Volatile and Particulate Activity into Cell (Ref. 1,4)

Cause

- Improper procedure for opening ruptured fuel can, handling ruptured fuel, dropping and breaking fuel element during handling

Consequence

- I-131 released due to handling ruptured fuel

Safety Feature

- Radiation monitors

2.2.6 Fuel Element Overheating (Ref. 4,7)

Cause

- Failure of equipment to handle fuel from pool to shear may leave fuel in air for extended period

Consequences

- Release of fission gas or fuel due to cladding failure
- Contamination of cell and ventilation filters

Safety Feature

- Ventilation system

2.2.7 Chopped Fuel Overheating (Ref. 4)

Cause

- Plugging of chute valves

Consequence

- Release of fission gas and fuel fines to cell during unplugging operations

Safety Feature

- Radiation monitor in chute

2.2.8 Irregular Length of Hulls (Ref. 4)

Cause

- Broken shear blade

Consequence

- May plug shear head and contaminate cell and ventilation filters

Safety Feature

- Visual observation and hull monitor

2.2.9 Shear Jammed (Ref. 4)

Cause

- Worn or frozen bearings

Consequences

- Damage to other parts of the shear
- Holdup of fuel in shear with possible overheating

Safety Features

- Visual observation
- Pressure alarms on hydraulic oil

2.3 Voloxidation

2.3.1 Escape of Powder from Reaction Vessel

Causes

- Rupture of reaction vessel because of corrosion, erosion, and warping resulting from reaction runwaway
- Rupture of moving seals

Consequence

- General contamination of the cell and an increased level of iodine, Ru, Cs, Kr, and tritium in the cell off-gas system

Safety Feature

- Cell off-gas system

2.4 Dissolving

2.4.1 Uncomplexed Fluoride in Dissolvent

Cause

- Fluoride must be used for dissolution of unirradiated or out-of-specification irradiated Pu oxide in fuel

Consequences

- Attack and dissolution of part of cladding hulls
- Corrosion of dissolver and ancillary equipment
- Equipment corrosion during acid recovery, acid recycle, and waste handling

Safety Feature

- Specific gravity monitor on dissolvent to dissolver

2.4.2 Pu-Rich Residue Settling in Dissolver, Lines, and Other Process Vessels

Cause

- Incomplete dissolution

Consequence

- Increased criticality potential

Safety Features

- Use of fluoride for mixed fuels

- Adherence to dissolubility specifications during fuel fabrication
- Double contingency principle

2.4.3 Overloading Capacity of Off-Gas System

Cause

- High initial dissolution rates of U_3O_8 in nitric acid

Consequences

- Filter pluggage
- Off-gas system failure, potential for stack release

Safety Feature

- Limiting the addition rate of fuel to semi-continuous dissolver

2.4.4 Precipitation of Pu Polymer

Cause

- Acid depletion in dissolver

Consequence

- Increased criticality potential

Safety Feature

- Inherently minimized by semi-continuous dissolution because sufficient nitric acid is in the dissolver before fuel addition is started

2.4.5 Overpressurization of Stored Fuel Cans

Cause

- Fission gas evolution from sheared fuel cans

Consequence

- Release of airborne activity to the cell ventilation system

Safety Feature

- Air purge through container to off-gas treatment module

2.4.6 Contact of Sheared Fuel at a Temperature About 300°C Above Boiling Point of Dissolver Solution

Cause

- Failure to cool

Consequence

- Pressurization of dissolver

Safety Features

- Procedural controls
- Temperature monitor

2.4.7 Zirconium Fire

Cause

- Spontaneous reaction of zirconium fines or reactive surfaces of hulls

Consequences

- Airborne activity
- Equipment damage
- Filter pluggage
- Loss of process control

Safety Features

- Hull passification with NaOH
- Air drying with heated argon
- Cleanup of fines before significant accumulation

2.4.8 Zirconium Explosion

Cause

- Zr fines escaping from the basket and settling in the dissolver

Consequences

- Airborne activity
- Equipment damage
- Off-gas system damage

Safety Feature

- Periodic flushing of the dissolver

2.4.9 Explosion in the Iodine Adsorber (Ref. 5,6,7)

Causes

- Autocatylic decomposition of silver azides formed from the reaction of ammonia and silver
- Reactor flush with ammonium hydroxide

Consequence

- Release of iodine from adsorber

Safety Feature

- Procedural control

2.4.10 Dissolver Seal Failure (Ref. 4,6)

Cause

- Gasket failure

Consequence

- May overload DOG system

Safety Features

- Interlock between dissolver vacuum and steam supply

2.4.11 Overconcentration in Dissolver (Ref. 1,2,5,7)

Causes

- Low-level control point reached or high pressure occurs
- Failure of fail-safe electrical interlocks to terminate steam supply
- Failure of operator to observe

Consequence

- Criticality potential

Safety Feature

- Fail-safe electrical interlocks to terminate steam supply

2.4.12 Pressurization of the Dissolver (Ref. 1,2,4,5)

Causes

- Pluggage of off-gas eductor
- Failure of off-gas control valves
- Loss of cooling to downdraft condensers
- Loss of normal cooling water
- Loss of steam supply

Consequences

- Discharge of off-gas to cell ventilation
- Dissolver solution to cell sump

Safety Features

- Automatic activation of emergency cooling water
- Pressure instrumentation

2.4.13 Dissolver Leakage (Ref. 1,2,5)

Causes

- Gasket failure
- Corrosion
- Valve failure

Consequence

- Release of material from primary containment

Safety Feature

- Cell sump alarm

2.4.14 Self-Concentration of Dissolver Solution (Ref. 5)

Cause

- Evaporation losses due to high temperature and/or prolonged storage

Consequence

- Increased criticality potential

Safety Feature

- Weight factor and density instrumentation

2.4.15 Low H^+/Pu Ratio in Dissolver Solution (Ref. 4,5)

Causes

- Failure of acid control valve or pump
- Mistake in dissolver acid solution makeup
- Prolonged reflux boiling of dissolver solution

Consequence

- Potential criticality in waste system due to plutonium polymer formation

Safety Feature

- Dual density instrumentation and safety analysis

2.4.16 Inadequate Nuclear Poison in Dissolver or Leach Solution (Ref. 4,5)

Causes

- Operator error
- Poison addition system malfunction

Consequence

- Potential nuclear criticality if corrective action is not taken

Safety Feature

- Sample analysis and flow instrumentation on poison addition system

2.4.17 High Fuel Loss in Leached Fuel Fragments (Ref. 1,5)

Causes

- Low acidity in dissolver solution
- Inadequate time or temperature in dissolution cycle

Consequence

- Potential criticality in storage pool if gross amounts of fuel are present in packaged cladding waste

Safety Feature

- Gamma spectrometer at packaging station

2.4.18 Inadequate Cladding Rinse (Ref. 5)

Cause

- Operator error

Consequence

- Increased entrainment of radioactive material into cell atmosphere during transfer of dissolver basket to cladding monitor

Safety Feature

- Sampling and radiation instrumentation

2.4.19 Charge of Inadequately Cooled Fuel (Ref. 5)

Causes

- Incorrect fuel assembly identification
- Erroneous instructions

Consequence

- Release of radioiodine to stack

Safety Features

- Iodine monitors in DOG system
- Certified records on incoming fuel

2.4.20 Malfunction of DOG Iodine Absorbers (Ref. 5,7)

Causes

- Excessive or insufficient reactor temperature
- High humidity in feed gas
- Failure of DOG heater
- Channeling

Consequence

- Iodine release from absorbers

Safety Feature

- Three radioiodine monitors, temperature recorder/controller instrumentation on heater unit, and monitoring instrumentation in rare gas recovery system

2.4.21 Excessive Interaction of Fuel External to Dissolver

Causes

- Nearby fuel rods in assemblies
- Fuel fragments from broken rods

Consequence

- Slight reduction in criticality safety margin

Safety Features

- Procedural control
- Neutron monitor

2.4.22 Failure of Cladding Monitor (Ref. 1)

Causes

- Power failure
- Electronic failure

Consequence

- Increased criticality potential in cladding storage

Safety Features

- Emergency power
- Dual instruments
- Regular calibration

2.4.23 Excessive Pressure in Water Wash Compartment Except During Basket Exchange (Ref. 4)

Cause

- Hatch cover not in place

Consequence

- May overload DOG-VOG system. Excessive pressure drop on DOG-VOG filters

Safety Feature

- Pressure monitor

2.4.24 Dissolver Pot Coils not Submerged During Shutdown

Cause

- Operator error

Consequence

- High loss of volatiles to cell atmosphere

Safety Features

- Density instrumentation

2.4.25 High Liquid Level in Dissolver (Ref. 4)

Cause

- Failure of air lift and level controller; personnel, valving, instrument, alarm, process, procedural, and pump difficulties; and piping errors, and equipment damage

Consequence

- Overflow of dissolver solution to cell pump

Safety Feature

- High level alarm

2.4.26 Absence of Basket in Dissolver (Ref. 4)

Cause

- Failure to replace empty basket after removing hulls

Consequences

- Increased criticality potential due to geometry change
- Release of gaseous fission products to atmosphere

Safety Feature

- Alarm activated by abnormally low position of basket cover

2.4.27 Transfer Error of Dissolver Solution

Cause

- Valving error, personnel difficulties, piping error, equipment failure, and procedural difficulties

Consequence

- Transfer solution to other vessels or to cell sump

Safety Features

- Clearly labeled valves
- Gang valves
- Liquid level indicators
- Dedicated piping

2.4.28 Explosion in Dissolver Vessel or Hold Tanks

Cause

- Hydrogen evolution during shutdown

Consequence

- Radioactive aerosol and liquid to cell

Safety Feature

- Off-gas purge and explosimeter

2.4.29 Suckback

Cause

- Eructation and pressurization of dissolver

Consequence

- High radiation levels in areas occasionally occupied by personnel

Safety Feature

- Seal pot

2.4.30 Siphoning

Cause

- Design error

Consequence

- Transfer of dissolver contents to another vessel or to the cell sump

Safety Feature

- Vacuum break

2.5 Solvent Extraction*

2.5.1 Plutonium Concentration in a Solvent Extraction Contactor Increases Beyond Normal Values

Causes

- Low acid concentration in contactors
- Excessive nitrous acid in organic product from the 1A' contactor (1AP' stream)
- Low reductant concentration in scrub stream

Consequence

- Three-fold concentration of plutonium

Safety Features

- Neutron monitors on the contactor
- Analyses of the exit concentrations
- Analyses of scrub stream
- Geometrically safe contactor for 25-gm Pu/liter solutions

2.5.2 Potential for Solvent Fire (Ref. 1)

Cause

- Temperature above flash point due to overheating organic storage tank

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* Nomenclature in this section is consistent with that presented in Reference 47.

Consequence

- Release of portion of fission product inventory

Safety Features

- Potential sources of ignition are eliminated
- Cells handling solvent are equipped with foam generating fire-extinguishing equipment
- Solvent vessels that are required to be heated are heated with hot water
- Flame arrestors separate the ventilation system for equipment containing low-boiling hydrocarbons from the other parts of the VOG
- Organic storage tanks are cooled with cooling coils

Cause

- Solvent leak sprays on concentrator exceeds flash point

Consequence

- Plutonium content up to 5 g/min of leakage

Safety Features

- Potential sources of ignition are eliminated
- Instrumentation detects any organic leakage
- Cells handling solvent are equipped with foam generating fire-extinguishing equipment
- Flame arrestors separate the ventilation system for equipment containing low-boiling hydrocarbons from the other parts of the VOG
- Vessels and piping provide primary confinement. Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system.

2.5.3 Potential Backup of Radioactivity by Air Lines (Ref. 1)

Cause

- Loss of pressure on system

Safety Feature

- Cold side of piping above highest point of hot side. Positive pressure on cold side when open to hot side; steam lines purged with air when steam cut off. Process jets controlled by gang valve assemblies. Correct valve sequence determined by programmer.

2.5.4 Potential for Buildup of Unsafe Amounts of Fissile Material in Organic Storage Tank (Ref. 1,4)

Cause

- Abnormally high losses in 1CW (spent solvent) followed by plugging of aqueous outlet of SB column (washed solvent) decanter

Consequence

- Criticality hazard. Losses high enough to result in decanter plugging are unknown; requires two additional failures for criticality

Safety Feature

- Criticality prevented by concentration control. Sampling capability and online and offline analyses of all major product and waste streams. Neutron monitors. Neutron and gamma shielding between process equipment and personnel. Flow rates out of decanters and separators are monitored.

Cause

- Plugging of aqueous outlet of 1CU (U product) decanter

Consequence

- Criticality hazard. Primary failure unlikely. Requires two additional failures for criticality.

Safety Feature

- Concentration control. Sampling capability for online and offline analyses. Neutron monitors. Neutron and gamma shielding between process equipment and personnel. Flow rates from decanters and separators are monitored.

2.5.5 Potential for Abnormal Accumulation of Fissile Material by Plutonium Reflux in 1A Contactor (Ref. 1,4)

Cause 1

- Loss of 1AS acid

Consequence

- Decreased margin of safety, particularly during HAW rework. Requires two additional failures for criticality.

Safety Feature

- Neutron monitors. Sepcific gravity monitoring of scrub streams. Extracting contactors designed to be geometrically safe up to 25 g fissile Pu/liter.

Cause 2

- Addition of reductant to feed (1AF) or scrub (1AS) streams of 1A contactor

Consequence

- Potential criticality due to rework

Safety Features

- Neutron monitors
- Rerun equipment to recover and recondition materials
- Extracting contactors designed to be geometrically safe up to 25 g fissile Pu/liter
- Scrub stream monitors for specific gravity
- Aqueous waste streams monitored for Pu content

2.5.6 Potentially Unsafe Feed Concentration (Ref. 1)

Cause 1

- Incorrect high concentration from leacher reservoir

Consequence

- Criticality hazard, but would require more than two additional failures

Safety Features

- Samplers and online instruments to measure specific gravity, chemical composition, and isotopic composition in feed clarification receipt tank, uranium product hold tank, and plutonium/uranium evaporator concentrate

- Neutron monitors
- Neutron and gamma shielding between process equipment and personnel
- Extracting contactors designed to be geometrically safe up to 25 g fissile Pu/liter

Cause 2

- Steam connected to cooling coil during flushing is not removed

Consequences

- Criticality would require two additional failures
- Initial criticality followed by pulsing

Safety Features

- Samplers and online instruments to measure volume, specific gravity, chemical composition, and isotopic composition, of feed clarification tank, uranium product hold tank, and plutonium/uranium evaporator concentrate
- Neutron monitors
- Neutron and gamma shielding between process equipment and personnel
- Extracting contractors designed to be geometrically safe up to 25 g fissile Pu/liter
- First cycle feed tank cooled by internal cooling coils and equipped with temperature instrumentation
- First cycle feed tank permits addition of dilute nitric acid

Cause 3

- Uranium product stream (1CU) from 1C contactor reworked at unsafe concentration levels

Consequences

- Criticality would require two additional failures
- Criticality burst

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- Neutron monitors

- Neutron and gamma shielding between process equipment and personnel
- Extracting contractors designed to be geometrically safe up to 25 g fissile Pu/liter

2.5.7 Potential for Excessive Plutonium Loss to Aqueous Waste (Ref. 1,2,4)

Cause

- High feed rate or concentration

Consequence

- Direct criticality hazard

Safety Features

- Samplers and inline instruments to measure volume, specific gravity, chemical composition, and isotopic composition of feed clarification receipt tank, uranium product hold tank, plutonium/uranium evaporator concentrate tank.
- Neutron monitors
- Inline monitors for detection of fissile materials in solvent wash wastes
- Plutonium content of aqueous waste streams is monitored

Cause

- Low organic flow rate

Consequence

- Potential criticality hazard due to rework

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- Neutron monitors
- Inline monitors to detect fissile material in solvent wash wastes

2.5.8 Potential for Excessive Product Loss to Spent Organic Effluent (Ref. 1,2)

Cause

- Low aqueous strip solution flow ratio

Consequence

- Reduced criticality safety margin. At least two additional failures required for criticality. (U alone is safe below design basis enrichment of 1.6% Uranium-235.)

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- Neutron monitors
- Inline monitors for detection of fissile materials in solvent wash wastes
- Flow rates monitored at exits of decanters and separators

2.5.9 Flow Reduction or Interruption of Scrub Streams (1AS or 1AS') to 1A and 1A' Contactors

Cause

- Malfunction of flow controller

Consequences

- Insufficient decontamination in co-decontamination cycle
- Personnel radiation in product systems

Safety Feature

- Flow rates monitored at exits of decanters and separators

2.5.10 Loss of Organic Flow to a Contactor (Ref. 2)

Cause

- Pump failure

Consequence

- Loss to waste stream

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- Neutron monitors
- Aqueous waste streams monitored for plutonium content

2.5.11 Low Temperature in Scrub Stream (1AS) to 1A Contactor

Cause

- Failure of scrub heater

Consequences

- Loss of DF* in code contamination cycle
- Personnel radiation hazard only if DF greatly reduced

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- Cooling water pumps and heaters for temperature control in solvent extraction connected to emergency electrical system

2.5.12 Low Temperature in 1C Contactor (Ref. 4)

Cause

- Failure of heater or controller

Consequence

- Loss of U to waste stream (1CW) leaving 1C contactor. Precipitation of U in general purpose evaporator. Remote criticality possibility.

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- Cooling water pumps and heaters for temperature control in solvent extraction connected to emergency electrical system

* Decontamination factor

2.5.13 Accumulated Solvent in Cells (Ref. 4)

Cause

- Leak in equipment or piping

Consequences

- Contaminated cells, equipment, and piping
- Increased potential for fire

Safety Features

- Rerun equipment provided to recover and recondition materials resulting from abnormal occurrences such as overflows, leaks, or misdirected process streams. Equipment includes digester to destroy organic material before it is evaporated.
- Vessels and piping provide primary confinement. Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system. Airborne material is filtered.
- Sump contents moved by steam jet to geometrically safe collection tank equipped with decanter and sampler

2.5.14 Emulsion in Solvent Washer (Ref. 4)

Causes

- Accumulation of finely divided solids
- Failure of solvent filters
- Neutralization of wash solution by entrainment between caustic and acidic washers
- Excessive pulsing

Consequences

- Carbonate or caustic entrainment to solvent extraction equipment
- Neutralization of acid and formation of plutonium polymer

Safety Feature

- All aqueous streams exiting solvent-extraction units (contactors) pass through a centrifugal separator to remove entrained organic material and to prevent a possible explosion hazard in downstream operations such as evaporation.

2.5.15 High Plutonium Losses in Waste Streams (2AW or 3AW) from 2A or 3A Contactors

Cause 1

- Low acid concentration in the bank caused by insufficient acid addition to either feed or scrub streams

Safety Features

- Specific gravity of scrub streams monitored continuously. Alarms alert personnel to abnormal scrub acidity.
- To avoid reflux, the three plutonium-containing cycles have dual flow instruments on the feed, extractant, and strip streams. These instruments are supplemented with neutron monitors and alpha monitors; the aqueous scrub and waste streams use conductivity instruments. Spent solvent streams employ dual alpha monitors and alarms.
- Aqueous waste streams monitored for plutonium content

Cause 2

- Low flow in extractant streams (2AX or 3AX) from 2A or 3A contactors

Safety Features

- Sampling capability for online and offline analyses required on all major product and waste streams exiting the contactors
- To avoid reflux, the three plutonium-containing cycles have dual flow instruments on the feed, extractant, and strip streams. These instruments are supplemented with neutron monitors and alpha monitors; the aqueous scrub and waste streams use conductivity instruments. Spent solvent streams employ dual alpha monitors and alarms.
- Aqueous waste streams continuously monitored for plutonium content

Cause 3

- Plutonium(III) not oxidized to Plutonium(IV) before entering 2A or 3A contactors

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- To avoid reflux, the three plutonium-containing cycles have dual flow instruments on the feed, extractant, and strip streams. These instruments are supplemented with neutron monitors and alpha monitors; the aqueous scrub and waste streams use conductivity instruments. Spent solvent streams employ dual alpha monitors and alarms.
- Aqueous waste streams monitored for plutonium content

Cause 4

- Insufficient mixing in 2A or 3A contactors

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- To avoid reflux, the three plutonium-containing cycles have dual flow instruments on the feed, extractant, and strip streams. These instruments are supplemented with neutron monitors and alpha monitors; the aqueous scrub and waste streams use conductivity instruments. Spent solvent streams have dual alpha monitors and alarms.

Cause 5

- Flooding in bank

Safety Features

- Rerun equipment provided to recover and recondition materials resulting from abnormal occurrences such as overflows, leaks, or misdirected process streams. Equipment includes digester to destroy organic material before it is evaporated.
- Vessels and piping provide primary confinement. Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system. Airborne material is filtered.

Consequence

- High plutonium in 1AW concentrator. Increased potential for plutonium polymer and plutonium losses in contactor.

2.5.16 High Plutonium Losses in Waste Streams (2BW or 3BW) from 2B or 3B Contactors

Cause 1

- Low flow of extractant streams (2BX or 3BX) to 2B or 3B contactors; low reductant concentration

Safety Features

- Sampling capability and online and offline analyses for all major product and waste streams
- Acidity and temperature controls reduce plutonium losses during clarification and solvent extraction (feed solution is kept below 40°C) and reduce potential for criticality
- To avoid reflux, the three plutonium-containing cycles have dual flow instruments on the feed, extractant, and strip streams. These instruments are supplemented with neutron monitors and alpha monitors; the aqueous scrub and waste streams use conductivity instruments. Spent solvent streams employ dual alpha monitors and alarms.

Cause 2

- Flooding of scrub streams (2BS or 3BS) to 2B or 3B contactors

Safety Features

- Rerun equipment provided to recover and recondition materials resulting from abnormal occurrences such as overflows, leaks, or misdirected process streams. Equipment includes digester to destroy organic material before it is evaporated.
- Vessels and piping provide primary confinement. Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system. Airborne material is filtered.

Consequence

- High plutonium in low activity waste concentrator

2.5.17 High Plutonium Concentration in 2A Contactor (Ref. 4)

Cause

- Inadequate dilution of recycled off-spec product

Consequence

- Plutonium loss to waste stream (2AW) from 2A contactor and high plutonium in low activity waste concentrator

Safety Features

- Neutron monitors
- To avoid reflux, the three plutonium-containing cycles have dual flow instruments on the feed, extractant, and strip streams. These instruments are supplemented with neutron monitors and alpha monitors; the aqueous scrub and waste streams use conductivity instruments. Spent solvent streams employ dual alpha monitors and alarms.
- Aqueous waste streams are continuously monitored for plutonium content

2.5.18 Excess Gamma Activity in Plutonium Product (Ref. 4)

Cause 1

- Low flow in scrub streams (2AS or 3AS) to 2A or 3A contactors

Safety Features

- Sampling capability for online and offline analyses required on all major product and waste streams existing the contactors
- Flow rates at exits of decanters and separators are monitored and alarms given for abnormal flows

Cause 2

- Flooding of 2A or 3A contactors

Safety Features

- Rerun equipment provided to recover and recondition materials resulting from abnormal occurrences such as overflows, leaks, or misdirected process streams. Equipment includes digester to destroy organic material before it is evaporated.

- Vessels and piping provide primary confinement. Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system. Airborne material is filtered.

Cause 3

- Improper acid concentration in scrub streams

Safety Features

- Sampling capability for online and offline analyses required on all major product and waste streams exiting the contactors
- Specific gravities of scrub streams monitored continuously
- Vessels and piping provide primary confinement. Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system. Airborne material is filtered. Equipment includes digester to destroy organic material before it is evaporated.

Cause 4

- Insufficient mixing action in 2A or 3A contactors

Safety Features

- Sampling capability for online and offline analyses required on all major product and waste streams exiting the contactors

Consequence

- Radiation hazard in plutonium loadout operations

2.5.19 Incorrect Material Transfer of Feed Chemicals, Product Materials, or Incorrect Materials

Causes

- Procedural errors
- Operational errors
- Piping/valving errors

Consequences

- Release of radioactive materials
- Process disruption
- Critcality potential

Safety Features

- Sampling capability for online and offline analyses required on all major product and waste streams exiting the contactors
- Samplers and online instruments to measure specific gravity, chemical composition, and isotopic composition in feed clarification receipt tank (1AF), uranium product hold tank (2EU), and plutonium/uranium evaporator concentrate (2BPE).
- Specific gravities of scrub streams monitored continuously
- To avoid reflux, the three plutonium-containing cycles have dual flow instruments on the feed, extractant, and strip streams. These instruments are supplemented with neutron monitors and alpha monitors; the aqueous scrub and waste streams use conductivity instruments. Spent solvent streams employ dual alpha monitors and alarms.
- Neutron monitors

2.5.20 Solvent Extraction System Contents Removed by Overflow

Causes

- Operator error
- Eructation

Consequence

- Release of radioactive material, usually to a sump

Safety Features

- Process areas sealed with high inward flow of air across openings to prevent escape of radioactive materials
- Rerun equipment provided to recover and recondition materials resulting from abnormal occurrences such as overflows, leaks, or misdirected process streams. Equipment includes digester to destroy organic material before it is evaporated.
- Explosive reaction between tributyl phosphate and concentrated nitric acid prevented by limiting temperature to <135°C

- Vessels and piping provide primary confinement. Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system. Airborne material is filtered.
- Tanks and evaporators equipped with high-liquid-level alarms
- Sump contents moved by steam jet to geometrically safe collection tank equipped with decanter and sampler

2.6 Product Evaporation

2.6.1 Potential Reaction Between TBP and UNH (Red Oil Explosion) in Product Concentrator (Ref. 1,4)

Cause 1

- Temperature increase due to failure of steam pressure cutoff system

Safety Features

- Interlocks automatically turn off steam supply to an evaporator if solution temperature exceeds control limit or if steam pressure exceeds control limit
- Pressure relief valve on steam supply to evaporator relieves at 32 psig
- Transfer of fissile material from favorable to unsafe geometry not possible as result of a single error

Cause 2

- Emulsion formation in 1C contactor

Safety Feature

- All aqueous streams exiting solvent-extraction units (contactors) go through a centrifugal separator to remove entrained organic material to prevent a possible explosion in an evaporator

Cause 3

- Organic phase present due to functional failure of decanter

Safety Features

- All aqueous streams exiting solvent-extraction units (contactors) go through a centrifugal separator to remove entrained organic material to prevent a possible explosion in an evaporator
- The plutonium product stream (3BP) from the 3B contactor is scrubbed with N-paraffin diluent to prevent plutonium precipitation by DBP formed from degraded TBP
- The uranium product stream (2EU) from the 2E contactor is scrubbed with N-paraffin diluent to remove dissolved organic material
- Evaporator feeds sampled and analyzed for organic material

Consequences

- Eructation/explosion
- Rupture of concentrator
- Release of plutonium and fission product inventories

2.6.2 Leaks in Tank Containing Concentrated Uranium-Plutonium Solutions (Ref. 4)

Cause

- Corrosion

Consequences

- Plutonium losses from the system
- Contamination of cell and cell filters

Safety Features

- Process areas sealed with sufficiently high air flow to prevent escape of radioactive materials
- Leakage from geometrically favorable equipment not capable of assuming a geometry significantly less favorable
- Transfer of fissile material from favorable to unsafe geometry not possible as result of a single error
- Reboilers and condensers of corrosion-resistant material with ample corrosion allowance

- *Vessels and piping provide primary confinement.* Cells provide secondary confinement. Spills in cell collect in sump and are returned to primary confinement system. Airborne material is filtered.
- Floor and sump of evaporator cells have stainless steel liner to prevent erosion of containment and pluggage of sump waste piping
- Sump contents are moved by steam jet to geometrically safe collection tank equipped with decanter and sampler
- Sump under 3BP evaporator is critically safe for receipt of evaporator contents

2.6.3 Overconcentration of Uranium/Plutonium Product (Ref. 4)

Cause

- Failure or maloperation of specific gravity instrument used to control steam flow

Consequence

- Criticality accident possible in product storage tank if undetected for considerable length of time as solid plutonium nitrate forms. Release of gaseous fission products to atmosphere. Contamination of cell and filter.

Safety Features

- Sampling capability for online and offline analysis required on all evaporator concentrates
- Interlocks automatically turn off steam supply to an evaporator if solution temperature exceeds control limit or if steam pressure exceeds control limit
- Pressure relief valve on steam supply to evaporator relieves at 32 psig
- Neutron monitors installed wherever fissile material can accumulate
- U colorimeter

2.6.4 Transfer Error in a Product Evaporator System

Cause

- Equipment (valve) failure

Consequence

- Radioactive material in an unintended location

Safety Features

- Administrative controls/procedures
- Transfer of fissile material from favorable to unsafe geometry not possible as result of a single error
- Product evaporators have dual specific gravity, low liquid level, and temperature instruments to automatically protect against overconcentration of fissile material by shutting off the steam supply
- Gang valve assemblies control all process jets. A programmer ensures correct sequence of valve operation.
- Evaporators have high- and low-liquid-level detectors and alarms

2.6.5 Coil or Tube-Bundle Failure

Cause

- Corrosion

Consequence

- Release of radioactive material to the steam condensate return system or cooling water return system

Safety Features

- Reboilers and condenser are of corrosion-resistant materials with ample corrosion allowance
- A regulator maintains positive air pressure in the coils when steam and water pressure are absent
- Steam and cooling water pressures are higher than pressures inside process vessels. Steam condensate and cooling water returns are continuously monitored. Radioactive returns are automatically diverted.
- Closed loop systems supply evaporators with steam and cooling water

2.6.6 Boilover

Cause

- Uncontrolled reaction in an evaporator

Consequence

- Release of radioactive material from primary containment

Safety Features

- All aqueous streams exiting solvent-extraction units (contactors) go through a centrifugal separator to remove entrained organic material to prevent a possible explosion in an evaporator
- Both gamma and neutron shielding between process equipment and personnel
- Explosive interaction between TBP and concentrated uranyl nitrate is prevented by: 1) Temperature in process when TBP and uranyl nitrate are present is limited to <135°C, 2) Interlocks automatically turn off steam supply to an evaporator if solution temperature exceeds control limit or if steam pressure exceeds limit, 3) Pressure relief valve on the steam supply to an evaporator relieves at 32 psig.
- Flow of steam to a coil controlled manually or automatically by a temperature-measuring system
- Floor and sump of evaporator cells have stainless steel liner to prevent erosion of containment and pluggage of sump waste piping
- Sump contents are moved by steam jet to geometrically safe collection tank equipped with decanter and sampler
- Sump under evaporator is critically safe for receipt of evaporator contents

2.6.7 Overflow of an Evaporator

Cause

- Equipment failure (e.g. valves, instruments, alarms, and electrical)

Consequence

- Loss of radioactive material to cell sump

Safety Features

- Process areas are sealed with a high air flow to prevent the escape of radioactive material
- Transfer of fissile material from a favorable to unsafe geometry must not be possible as a consequence of a single error
- Gang valve assemblies control all process jets. A programmer ensures correct sequence of valve operation
- Evaporators have high- and low-liquid-level detectors and alarms
- Floor and sump of evaporator cells have stainless steel liner to prevent erosion of containment and pluggage of sump waste piping
- Sump contents are moved by steam jet to geometrically safe collection tank equipped with decanter and sampler
- Sump under evaporator is critically safe for receipt of evaporator contents

2.6.8 Concentrated Fissile Material in Evaporator Condenser of Unsafe Geometry (Ref. 3)

Cause

- Bumping or eructation of product evaporator bottoms

Consequence

- Criticality in evaporator condenser

Safety Features

- Use of thermosyphon reboilers for evaporators makes for a low probability of bumping fissile material into a condenser tower
- Product evaporators have dual specific gravity, low liquid level, and temperature instruments to automatically protect against overconcentration of fissile material by cutting off the steam supply
- Interlocks automatically turn off steam supply to an evaporator if solution temperature exceeds control limit or if steam pressure exceeds control limit
- Evaporators of safe geometry have condensers of safe geometry

2.7 Waste Evaporation

2.7.1 Ruthenium Escapes to Stack

Cause

- Formation of volatile ruthenium compounds

Consequence

- Release of radioactive material

Safety Features

- Noncondensible vapors sent to the VOG
- Sugar added to suppress ruthenium volatility
- All condensers have gamma monitors

2.7.2 Leaks

Cause

- Corrosion

Consequence

- Release to sumps

Safety Features

- Titanium is used in place of stainless steel for construction of evaporators and reboilers
- Evaporators located in hot cells
- Adequate corrosion allowance provided in equipment design
- In the event of failure of the primary confinement system (vessels and piping), waste materials are released to a process cell, which provides effective secondary containment. Liquids go to collection sumps in the cell floor and are returned to primary confinement by a sump transfer jet. Sumps have liquid level alarms. Airborne materials go to process building ventilation system with the cell air
- Floor and sump of evaporator cells have stainless steel liners to prevent undue erosion of the containment and pluggage of sump waste piping

2.7.3 Transfer Error in the Evaporator System

Cause

- Equipment (valve) failure, human error

Consequence

- Radioactive material in an unintended location

Safety Features

- Administrative controls/procedures
- Evaporators are in hot cells

2.7.4 Coil or Tube Bundle Failure

Cause

- Corrosion

Consequence

- Release of radioactive material to the steam condensate return or cooling water return

Safety Features

- Adequate corrosion allowance provided in equipment design
- Closed-loop systems supply steam and cooling water to process equipment. Steam and cooling water are supplied at pressures higher than the pressures inside the process equipment.
- Steam condensate and cooling water from the evaporators are monitored and diverted automatically to the low-level waste system in the event of a tube failure

2.7.5 Boilover

Cause

- Uncontrolled reaction in an evaporator

Consequence

- Release of radioactive material from primary containment

Safety Features

- Evaporator feed decanted to remove floating organic material
- Steam pressure is limited to 25 psig to maintain the bottoms temperature below that necessary for a red-oil explosion
- In the event of failure of the primary confinement system (vessels and piping), waste materials are released to a process cell, which provides effective secondary containment. Liquids go to collection sumps in the cell floor and are returned to primary confinement by a sump transfer jet. Sumps have liquid level alarms. Airborne materials go to process building ventilation system with the cell air.
- A seal pot protects the evaporators from over-pressurization and from pressure surges that could force radioactive material through instrument and service lines
- Air sampling stations detect accidental measures
- The evaporator reboiler temperature is set to alarm and shut off the steam supply above 125°C
- Decomposition of any azides present is effected by acidifying all wastes before concentration
- All waste evaporator solutions are monitored for temperature and specific gravity
- Evaporator tanks are equipped with agitators to homogenize the solutions to prevent accumulations of organic material
- All condensers have overhead gamma monitors
- Floor and sump of evaporator cells have a stainless steel liner to prevent undue erosion of the containment and pluggage of sump waste piping
- Reboilers have antifoam addition lines

2.7.6 Overflow of a Feed or Bottom Tank

Cause

- Equipment failure (e.g. valves, instruments, alarms, electrical)

Consequence

- Loss of radioactive material to cell sump

Safety Features

- In the event of failure of the primary confinement system (vessels and piping), waste materials are released to a process cell, which provides effective secondary containment. Liquids go to collection sumps in the cell floor and are returned to primary confinement by a sump transfer jet. Sumps have liquid level alarms. Airborne materials go to process building ventilation system with the cell air.
- Air sampling stations detect accidental measures
- All waste evaporators and tanks have high- and low-liquid-level detectors and alarms
- The floor and sump of the evaporator cells have a stainless steel liner to prevent undue erosion of the containment and pluggage of sump waste piping

2.7.7 High Radioactivity in High-Activity Waste Evaporator Condensate (Ref. 5)

Causes

- Excessive entrainment
- Ruthenium volatilization

Consequence

- Increased radioactivity in off-gas

Safety Features

- Noncondensible vapors are sent to the VOG
- Sugar is added to suppress ruthenium volatility
- Floor and sump of the evaporator cells have a stainless steel liner to prevent undue erosion of the containment and pluggage of the sump waste piping

2.7.8 Overconcentration of Waste (Ref. 5)

Causes

- Improper operation of HAW evaporator
- Self-concentration

Consequence

- Formation of self-heating solids may result in vessel damage from localized heating if loss of agitation occurs

Safety Features

- All waste evaporator solutions monitored for temperature and specific gravity
- Waste batches from the evaporators are sampled at least daily. Thus, the presence of large quantities of plutonium in the waste would be detected within one day at the latest and corrective action taken.

2.7.9 Inadequate Vessel Cooling Capacity (Ref. 5)

Causes

- Excessive concentration
- Chilled water system failure
- Loss of normal electrical power

Consequence

- If corrective action is not taken, the water may become self-boiling, resulting in vessel pressurization and aerosol release to cell atmosphere

Safety Features

- The high-activity waste reboiler is water-cooled when waste is in the evaporator but is not being evaporated
- All waste evaporator solutions are monitored for temperature and specific gravity
- A pressure relief valve on the steam supply relieves pressure at about 32 psig

2.7.10 Leak of High-Level Waste Concentrate (Ref. 2,5)

Cause

- Vessel corrosion and valve failure

Consequence

- Release of radioactive material

Safety Features

- Routine visual inspection, sump inventory, sump alarm, temperature instrumentation, and material balance data
- Evaporator units are in hot cells
- Adequate corrosion allowance is provided in equipment design
- In the event of failure of the primary confinement system (vessels and piping), the waste materials are released to a process cell, which provides effective secondary containment. Liquids go to collection sumps in the cell floor and are returned to primary confinement by a sump transfer jet. The sumps have liquid level alarms. Airborne materials go the the process building ventilation system with the cell air.
- A waste accumulator tank receives and samples. HAW sump materials.

2.7.11 Explosion in High-Activity Waste Evaporator (Ref. 2,5,6)

Causes

- Hydrogen from radiolysis of waste
- Organic material in the feed to evaporator (e.g. solvent, ion exchange resin)

Consequence

- See Table 4-24 of (Ref. 6)

Safety Features

- Evaporator feed is decanted to remove floating organic material
- Hydrogen-gas explosion hazard is reduced by a continuous air purge through each vessel containing HAW. Instruments monitor the flow rate of the purge air.
- See also Incidents 2.7.3 through 2.7.6 under waste evaporator

2.8 Acid Recovery

2.8.1 Explosion in the ARU*

* Acid Recovery Unit

Causes

- Solvent in feed
- Temperature > 140°C

Consequences

- Release of radioactive material
- Personnel hazards

Safety Features

- Unit operated at reduced pressure to reduce operating temperature and corrosion rate
- ARU reboiler steam pressure is limited to 35 psig to prevent a violent reaction of entrained organic matter and nitric occurring above 140°C
- ARU reboiler temperature is set to alarm and shut off the steam supply above 140°C. Steam supply has relief valve.

2.8.2 Leaks in the ARU System

Cause

- Corrosion

Consequence

- Release to sumps

Safety Features

- Unit operated at reduced pressure to reduce operating temperature and corrosion rate
- Acid fractionator cell is lined with stainless steel to a height adequate to contain the liquid contents of the largest vessel in the cell

2.8.3 Eructation in ARU

Cause

- Foreign material in ARU feed

Consequence

- Release of radioactive material

Safety Features

- Unit operated at reduced pressure to reduce operating temperature and corrosion rate
- ARU reboiler steam pressure is limited to 35 psig to prevent a violent reaction of entrained organic matter and nitric acid occurring above 140°C
- Feed to ARU normally contains only traces of fissile material. This feed is monitored by stream sampling and analysis.
- ARU feed tank is equipped with instruments and components to detect and decant immiscible organic materials
- Sugar is added to the tower trays to suppress ruthenium volatility. Tower tray temperature sensors are interlocked with the flow controller on the sugar addition line to prevent sugar addition when tray temperature is <85°C.
- The decomposition of any azides present is effected by acidifying all wastes before concentration

2.8.4 High Radioactivity in Recycled Acid and/or Water (Ref. 4,5)

Causes

- Excessive entrainment or volatilization
- High radioactivity in feed to acid concentrator

Consequence

- Increased potential for excessive radioactivity release to atmosphere from the acid concentrator

Safety Features

- Unit is located in the canyon because of the activity in the feed (the overheads from the LAW evaporator)
- Feed to the ARU normally contains only traces of fissile material. Feed is monitored by frequent stream sampling and analysis.
- Chemicals, such as sugar, can be added to depress the volatility of any ruthenium in the fractionator
- Before release to stack, the overhead vapors pass through high efficiency filters. A gamma monitor is located downstream from the filters.

- The excess water vaporizer unit has sampling and monitoring equipment to verify the low concentrations of radioactive materials in process solutions
- The ARU feed tank is equipped with instruments and components to detect and decant immiscible organic materials
- Unit is operated at reduced pressure to reduce operating temperature and corrosion rate
- The ARU reboiler temperature is set to alarm and shut off the steam supply above 140°C. Steam supply has a relief valve.

2.8.5 Solvent Addition to ARU Feed Tank (Ref. 5)

Cause

- Severe solvent entrainment emulsion carryover

Consequence

- Increased potential for red-oil formation in acid concentrator

Safety Features

- The ARU feed tank is equipped with instruments and components to detect and decant immiscible organic materials
- Unit is operated at reduced pressure to reduce operating temperature and corrosion rate
- The ARU reboiler temperature is set to alarm and shut off the steam supply above 140°C. The steam supply has a relief valve.

2.8.6 Pressurization of Acid Absorber/Fractionator (Ref. 5)

Causes

- Loss of cooling water to off-gas condenser
- Off-gas flow restriction
- Inadequate vent header vacuum
- Excessive off-gas flow

Consequences

- Momentary discharge of contaminated vapors to the cell from the acid concentrator seal pot and acid fractionator seal pot

- Potential backup of contamination into cold area if seal pot and backflow systems malfunction and corrective action is not taken

Safety Features

- Unit is operated at reduced pressure to reduce operating temperature and corrosion rate
- A seal pot protects the ARU from overpressurization and pressure surges. The seal pot vents to the HLW cell.

2.9 Recovery Ion Exchanger

2.9.1 Uncontrolled Reaction Between Nitric Acid and Anion Exchange Resin in the PRC (Primary Recovery Column)

Cause

- Excessive temperature in the PRC

Consequence

- Release of radioactive material, eructation

Safety Features

- LAW concentrate is cooled below 60°C before it is fed to the PRC to avoid the potential for a violent exothermic reaction between the anion exchange and the nitric acid in the LAWC
- The bottom of the frame is enclosed by a sump to protect other canyon equipment and processes against contamination due to overflows and spillage from the PRC
- The column effluent weir is located at an elevation 5 inches above the top of the settled resin in the column to ensure that the resin is always submerged in liquid
- A resistance thermometer permanently mounted in the side of the column measures the feed stream and the heat buildup in the resin bed
- Level indicators with alarms indicate preoverflow conditions in recovery columns

2.9.2 Ion Exchange Resin Fire (Ref. 5,6)

Causes

- Resin-nitric acid reaction
- High acidity
- Resin temperature greater than 135°C

Consequences

- Release of radioactivity to the environment
- Explosion

Safety Features

- Evaporator concentrate is cooled below 60°C before it is fed to the column to avoid the potential for a violent exothermic reaction between the anion exchange resin and nitric acid in the feed
- The column effluent weir is located at an elevation 5 inches above the top of the settled resin in the column to ensure that the resin is always submerged in liquid
- Pretreatment and handling of resins according to procedures
- A resistance thermometer permanently mounted in the side of the column measures the feed stream and the heat buildup in the resin bed
- Nitrate concentrations limited to safe values

2.9.3 Overflow

Cause

- Pluggage, valving problems, operator errors, pump failures, and instrument failures

Consequence

- Potential release of radioactive material

Safety Features

- Level indicators with alarms indicate overflow conditions in recovery columns
- The bottom of the frame is enclosed by a sump to protect other canyon equipment and processes against contamination due to overflows and spillage from the PRC

2.9.4 Leakage

Cause

- Corrosion

Consequence

- Potential release of radioactivity

Safety Features

- Structural steel is protected from corrosion by a special paint
- The bottom of the frame is enclosed by a sump to protect other canyon equipment and processes aginast contamination due to overflows and spillage from the PRC

2.10 Off-Gas Treatment

2.10.1 Loss of Off-Gas Header Vacuum (Ref. 5)

Causes

- Flow restriction/pluggage
- Fan failure
- Loss of power
- Operating error

Consequence

- Untreated process off-gas is released to the cell atmosphere

Safety Feature

- Vacuum instrumentation and monitors on header; redundant fans; emergency power

2.10.2 High Radioactive Particulate Releases to Building Ventilation Filters (Ref. 5)

Causes

- Damaged process ducts or filters
- Maintenance errors

Consequence

- Increased radioactive particulate release to sand filter

Safety Feature

- Gas sampling in filter rooms

2.10.3 Filter Failure (Ref. 8)

Causes

- Dust explosions
- In-cell fires
- Condensation on HEPA filters

Consequence

- Release of radioactivity

Safety Features

- Periodic replacement, DOP tests, and inspection
- Pressure drop measurement
- Stack monitors

2.10.4 Off-Gas Heater Inadequately Heats Streams to Iodine Adsorbers (Ref. 5)

Causes

- Loss of electrical power
- Excessive flow
- Controller failure
- Excessive liquid entrainment
- Heater failure
- Operating error

Consequence

- Iodine removal efficiency is reduced

Safety Feature

- Temperature monitor and alarm

2.10.5 Iodine Removal Inadequate (Ref. 4,5)

Causes

- Low gas temperature
- High nitrogen oxide concentration
- Saturated iodine beds

Consequence

- Iodine accumulation in krypton solvent recovery

Safety Features

- Iodine monitors
- Temperature monitor and alarm
- Nitrogen oxide removal unit
- Humidity control

2.10.6 Process Vent System Pressurized (Ref. 1)

Cause

- Process upset (not a direct failure of the off-gas system)

Consequence

- Radioactivity discharged to sand filter and smaller amount to atmosphere

Safety Features

- High-pressure alarms on vessel off-gas system
- Iodine monitors on sand filter inlet and outlet
- Tall process stack

2.10.7 Excess Nitrogen Oxides in Vessel Off-Gas Iodine Adsorber Stream (Ref. 5)

Cause

- Nitrogen oxide scrubber malfunction, operating error

Consequence

- Iodine removal efficiency is reduced with increase in nitrogen oxides

Safety Feature

- Additional nitrogen oxide destruction unit

2.10.8 High Ruthenium Adsorber Bed Temperature (Ref. 5)

Causes

- Excessive ruthenium loading
- Inadequate bed cooling

Consequence

- Increased ruthenium through off-gas system

Safety Features

- Temperature alarms
- Two adsorber beds in series to remove the remaining ruthenium. Efficiency is monitored in between and downstream.
- Ruthenium monitors located between adsorption beds and downstream

2.10.9 High Krypton-85 Releases (Ref. 5)

Causes

- Operating error
- Poor rare gas recovery efficiency

Consequence

- Increased release of krypton-85 to the atmosphere

Safety Feature

- Radiation monitors on reprocessing facilities, krypton recovery system and stack

2.11 Uranyl Nitrate Receiving and Storage

2.11.1 Overflow from Tank

Causes

- Transfer error
- Instrument pluggage
- Instrument malfunction

- Procedural violation
- Valve malfunction
- Siphoning

Consequence

- Release of uranyl nitrate from primary containment

Safety Features

- Low activity of process material verified by sampling and analysis. Analytical equipment capable of detecting 1) one part Ru, one part Nb, and 50 parts phosphorous per million of total uranium, 2) gamma activity due to fission products and U-237 at 20% of the gamma activity of aged natural uranium, 3) beta activity due to fission products at 10% of the beta activity of aged natural uranium, and 4) alpha activity due to all transuranic elements at 1500 d/m/g of total uranium.
- Tanks are vented to the facility vent stack to prevent pressurization, suckback, or siphoning
- Dual liquid-level sensing systems with alarms signal potential overfilling of tanks
- A sump in the storage area collects spilled or leaked solution. A level alarm indicates accumulation of liquid

2.12 Uranyl Nitrate Evaporation

2.12.1 Pluggage of Instrument Lines and Sensors

Cause

- Solution temperature below the freezing point of concentrate

Consequences

- Overflow/spill of concentrate
- Release of radioactive material from primary containment

Safety Features

- Radioactivity of process material is low

- Temperature of concentrate transfer lines is kept above 105°C to prevent freezing of uranyl nitrate hexahydrate
- Denitrator feed pumps are steam heated
- Electric line heaters on the emergency power system
- Density and temperature monitors in reboiler
- Sump system ensures that material is collected in a favorable slab geometry
- Automatic floor flushing system beneath the evaporators and piping continuously monitors the specific gravity of the flush solution to give an early indication of any gradual leakage to the cell
- Sump liquid level instruments provide prompt detection in the event of a major leak

2.12.2 Steam Coil Leak in Evaporator Reboiler

Cause

- Corrosion

Consequence

- Radioactive material in steam condensate stream

Safety Features

- Alarm and diversion of steam condensate. The condensed steam lines from the evaporator reboilers have inline conductivity meters to indicate leakage of uranium solution into the condensate. In normal operation the condensed steam is returned to the utility plant. However if conductivity increases, the condensed steam is automatically rerouted to the UF_6 process area sump.
- Evaporator steam and cooling coils are pressurized with air when not in use to prevent contamination in the event of leaks

2.12.3 Cooling Coil Leak

Cause

- Corrosion

Consequence

- Traces of radioactive material in cooling water system

Safety Features

- Cooling water returned from evaporator condensers is monitored for radioactive material and is diverted to a retention basin
- Evaporator steam and cooling coils are pressurized with air when not in use to prevent contamination in the event of leaks. A mechanism is provided to test for leaks.

2.12.4 Overflow in Concentration System (Ref. 10)

Causes

- Over-concentration and instrument pluggage
- Procedural violations
- Transfer errors
- Valving errors
- Instrument malfunction
- Siphoning

Consequence

- Release of radioactive material from primary containment

Safety Features

- Dual liquid level sensing systems with alarms signal potential overfilling of tanks and reboilers
- A sump in the storage area collects spilled or leaked solution. A level alarm indicates accumulation of liquid
- Sump system ensures that material is collected in a favorable slab geometry
- Automatic floor flushing system beneath the evaporators and piping continuously monitors the specific gravity of the flush solution to give an early indication of any gradual leakage to the cell
- Sump liquid level instruments provide prompt detection in the event of a major leak

- A sump under the recovered acid tank has an alarm to detect leaks
- Steam pressure in the evaporator heating coils is kept below 80 psig (160°C) to prevent denitration
- Specific gravity and temperature instruments aid in controlling the uranium concentration in the evaporator reboiler
- Analytical equipment for analyzing incoming feed must be capable of reliably detecting 1) one part Ru, one part Nb, and 50 parts of phosphorus per million of total uranium, 2) gamma activity due to fission products and U-237 at 20% of the gamma activity of aged natural uranium and as measured in a high-pressure ionization chamber, 3) beta activity due to fission products at 10% of the beta activity of aged natural uranium, 4) alpha activity due to all transuranic elements at 1500 d/m/g of total uranium.
- Tanks are vented to the facility vent stack to prevent pressurization, suckback, or siphoning
- The recovered acid storage tank and the evaporator condensers are vented to the facility vent stack

2.12.5 High Uranium Concentration in Recovered Acid (Ref. 1,5,10)

Causes

- Evaporator "bumping"
- Entrainment in evaporator overheads

Consequence

- High uranium concentration in recovered acid

Safety Features

- The first- and second-thermosyphon evaporators are equipped with demister pads to remove entrained material from overhead vapors. The inherently stable operation of a thermosyphon evaporator has a low probability of "bumping."
- Steam pressure in the evaporator heating coils is kept below 80 psig (160°C) to prevent denitration
- Limit switches close the steam supply if the steam pressure in the reboiler shell or the bottoms temperature exceed preset values

- Sudden pressure surges in the evaporator are relieved through a seal pot
- Nitric acid recovered from evaporator overheads or supply denitrator off-gas is monitored for gamma activity and sampled for analysis

2.13 Uranium Denitration

2.13.1 Denitrator Eructation (Ref. 5,44)

Cause

- Uncontrolled, rapid reaction of TBP with uranyl nitrate at 140 to 160°C

Consequences

- Release of radioactive material from primary containment
- Airborne activity
- Fire and explosion from flammable reaction products

Safety Features

- An accountability tank is used to receive uranyl nitrate solution from the solvent extraction facility. Tank contents are sampled and analyzed to determine that the solution meets specifications.
- Analytical equipment for analyzing incoming feed and capable of reliably detecting one part Ru, one part Nb, and 50 parts phosphorus per million parts of total uranium
- Before evaporation, entrained process solvent is removed by decantation to eliminate a hazard in subsequent process steps. Tributyl phosphate decomposes rapidly when heated with nitrate at temperatures in the range 140 to 160°C.
- Feed storage tanks used as decanters have inlet baffles which maintain smooth blending of incoming solution with stored solution and avoid re-entrainment of organic layers
- The surface of stored uranyl nitrate solutions can be inspected for the presence of floating organic material
- The evaporator feed pump cuts off automatically to avoid inadvertently pumping the evaporator feed tank empty

- A vacuum cleaner system discharges solids into the uranium oxide drumout facility
- Continuous, rather than batch, operation

2.13.2 Pressurization of Denitrator (Ref. 5)

Causes

- Pluggage of off-gas line
- Loss of vacuum (e.g. steam jet failure)
- Off-gas valving error

Consequences

- Fumes released from denitrator (fume-out)
- Liquid released from denitrator (foam-out)

Safety Features

- Denitration fumes are exhausted to a nitric acid fume scrubber and an acid recovery unit. A negative pressure on the denitrator and dust filters ensures proper off-gas flows. The vacuum is controlled automatically
- Automatic control is provided for the feed rate, the calciner temperature, and the level of solution in the fume scrubber. High and low alarms are provided for the feed flow rate. A high temperature alarm is provided for the calciner temperature. Alarms are also provided for the pressure drop across the filters and the liquid level in the fume scrubber
- Steam-operated jets provide denitrator off-gas vacuum (as a backup for the electrically-driven exhausters). If adequate vacuum cannot be maintained (automatically or manually) in the denitrator to prevent fumes from entering the personnel areas, the denitrator is shut down.
- Constant air monitors provide continuous, redundant detection of airborne alpha contamination. Equipment which requires routine maintenance or is prone to leakage (e.g. solids feeders and drain valves) is enclosed in confinement boxes maintained at subatmosphere pressure

- Airborne particulates, aerosols, or vaporized process materials resulting from component failure enter the cell atmosphere and are routed to the building ventilation system equipped with a deep-bed fiberglas filter and two HEPA filters in series. Process exhaust ventilation is provided near equipment connections to collect dusts and to limit the spread of contamination.

2.13.3 High Uranium Concentration in Recovered Acid (Ref. 10)

Cause

- Failure of uranium oxide filters

Consequence

- Contamination of process solutions

Safety Features

- Vapors from the continuous denitrator are filtered through a bank of 10-micron sintered stainless steel filters. These filters are blown back with dry air periodically to prevent pluggage from uranium oxide dust.
- Denitration fumes are exhausted to a nitric acid fume scrubber and an acid recovery unit. A negative pressure on the denitrator and dust filters ensures proper off-gas flows. The vacuum is controlled automatically.
- Automatic control is provided for the feed rate, the calciner temperature, and the level of solution in the fume scrubber. High and low alarms are provided for the feed flow rate. A high temperature alarm is provided for the calciner temperature. Alarms are also provided for the pressure drop across the filters and the liquid level in the fume scrubber
- Nitric acid from evaporator overheads or denitrator off-gas is monitored for gamma activity and sampled for analysis

2.14 Uranium Reduction

2.14.1 Hydrogen Explosion (Ref. 5,10)

Causes

- Hydrogen leaked from reductor ignited by external burner

- Hydrogen ignites inside reductor due to incorrect startup procedure, e.g., failure to purge
- Hydrogen ignites in off-gas scrubber

Consequences

- Release of radioactive material from primary containment
- Injury to operating personnel
- Damage to off-gas filters

Safety Features

- Pressure drop across the reductor off-gas filters is measured. Filter elements are sequentially blown back with nitrogen to provide periodic cleaning. The off-gas is continually analyzed for hydrogen gas content, and the inlet gas flows are controlled to maintain a prescribed hydrogen gas content range in the off-gas.
- A flame arrestor of the off-gas stream protects against the flashback of hydrogen
- The product and off-gas streams in the reduction area are totally enclosed within a sealed system. Opening of the system is performed only during a shutdown period for inspection, maintenance, or equipment changeout. A dust and fume-collecting snorkel is provided in the area and positioned adjacent to a component when it is to be opened.
- Hydrogen detectors and alarms

2.14.2 Overpressurization of Reductor (Ref. 10)

Cause

- Line or filter pluggage and failure of gas feed pressure controller

Consequence

- Uranium contamination of area

Safety Features

- Excessive particulate filter loading or failure is signaled by pressure differential alarms

- Pressure drop across the reductor off-gas filters is measured. Filter elements are sequentially blown back with nitrogen to provide periodic cleaning. The off-gas is continually analyzed for hydrogen gas content, and the inlet gas flows are controlled to maintain a prescribed hydrogen gas content range in the off-gas.
- The product and off-gas streams in the reduction area are totally enclosed within a sealed system. Opening of the system is performed only during a shutdown period for inspection, maintenance, or equipment changeout. A dust and fume-collecting snorkel is provided in the area and positioned adjacent to a component when it is to be opened.
- Powder level measurement in the incoming uranium-oxide feed vessel provides continuing protection from powder clogging the system or loss of the powder seals on either side of the reduction area.
- The reductor is equipped with rupture discs

2.14.3 Fire in Ammonia Dissociator Cubicle (Ref. 10)

Cause

- Leakage of ammonia or hydrogen

Consequence

- Equipment damage

Safety Features

- Fire alarm
- The ammonia storage tank is equipped with a rupture disc. The ammonia dissociator unit is equipped with a high-temperature alarm. The cubicle can be flooded with inert gas.

2.14.4 Reductor Malfunction (Ref. 11)

Causes

- Filter pluggage and overpressurization
- Filter failure
- Powder clogging

Consequence

- Release of uranium oxide and hydrogen

Safety Features

- Pressure drop across the reductor off-gas filters is measured. Filter elements are sequentially blown back with nitrogen to provide periodic cleaning. The off-gas is continually analyzed for hydrogen gas content, and the inlet gas flows are controlled to maintain a prescribed hydrogen gas content range in the off-gas.
- Excessive particulate filter loading failure is signaled by pressure differential alarms
- The reductor is equipped with rupture discs
- The reductor off-gas is filtered through a metal filter which has a filtration rating of at least 30 microns. A backup filter is permanently installed so that filtration is maintained even in the event of deterioration of a primary filter unit.
- Pressure drop across the reductor off-gas filters is measured. Filter elements are sequentially blown back with nitrogen to provide periodic cleaning. The off-gas is continually analyzed for hydrogen gas content, and the inlet gas flows are controlled to maintain a prescribed hydrogen gas content range in the off-gas.
- Powder level measurement in the incoming uranium-oxide feed vessel provides continuing protection from powder clogging the system or loss of the powder seals on either side of the reduction area
- Alarms reveal high- and low-powder-level situations in the transfer vessel between the two hydro-fluorination stages, the uranium fluoride seal vessel, and the uranium fluoride storage hopper

2.15 Hydrofluorination

2.15.1 Uranium Fluoride Release (Ref. 11)

Cause

- Spills from piping, conveyors, or containers

Consequences

- Inhalation by operating personnel

- Skin contamination of operating personnel
- 0.05 kg uranium released from stack

Safety Features

- The fluorinator off-gas is filtered and scrubbed before discharge to the atmosphere
- The off-gas is scrubbed with KOH solution in an absorber to remove residual HF
- The off-gas scrubber has high- and low-liquid-level alarms, a low-pH alarm, a backup solution pump, and a sampler
- Scrubbers have mist eliminators on the vapor discharge lines
- Alarms reveal high- and low-powder-level situations in the transfer vessel between the two hydrofluorination stages, the uranium fluoride vessel, and the uranium fluoride storage hopper
- Dust from the uranium fluoride solids handling equipment are vented to a uranium fluoride dust collection system (two filters) and sent to the fluorinator feed blender
- Process exhaust ventilation is provided near equipment connections to collect dust and limit spread of contamination
- Constant air monitors are provided in the hydrofluorination area
- Constant air and fluorine monitors provide early detection of process leaks. Airborne materials are routed to a ventilation system consisting of a heater, a roughing filter, and two high efficiency filters in series (Exxon). Local exhaust ventilation removes much of the vapor to process scrubbers.
- A vacuum cleaner system discharges spilled solids to the fluorinator fines system, which also collects fines from the fluorinator product filter
- Materials of construction for the uranium fluoride system are Inconel® and Monel® (Inconel and Monel are trademarks of Huntington Alloys, Inc.)

2.15.2 Hydrofluorinator Overpressurization (Ref. 10)

Cause

- Steam valve fails open, line blockage

Consequence

- Release of HF to scrubber

Safety Features

- Steam relief valves
- Pressure alarms indicate unsatisfactory pressure drop conditions on the off-gas filters
- Constant air monitors are provided in the hydrofluorination area
- The two filters are electrically heated to prevent moisture condensation. They are blown back periodically with hot nitrogen to prevent pluggage.
- Hydrofluorination vessel temperatures are controlled by regulated steam cooling
- High temperature alarms are provided for the reactor vessels

2.15.3 HF Release (Ref. 5,10,11)

Causes

- Leak in transfer line
- Leak in valve
- Gasket failure
- Damaged equipment
- Corrosion

Consequences

- Chemical hazard to operating personnel
- 10 kg HF released to ventilation stack (Ref. 17)

Safety Features

- The fluorinator off-gas is filtered and scrubbed before discharge to the atmosphere
- The off-gas is scrubbed with KOH solution in an absorber to remove residual HF
- The off-gas scrubber has high- and low-liquid-level alarms, a low-pH alarm, a backup solution pump, and a sampler
- Scrubber solutions containing KF are reacted with lime to precipitate calcium fluoride

- Materials of construction for the uranium fluoride system are Inconel® and Monel®

2.16 Fluorination

2.16.1 Fluorine or Uranium Fluoride Release (Ref. 1,5,10,11)

Causes

- Leaks in piping, valves, or gaskets
- Damaged equipment
- Corrosion

Consequences

- Chemical hazard to operating personnel
- Fluorine released to roof vents (Ref. 11)
- Fluorine released from leak (Ref. 10)

Safety Features

- Fluorine supply line from fluorine generation facility to the process building is contained in a secondary enclosure. A monitor detects leaks in the primary pipe.
- Valving and flow measuring equipment are in ventilated enclosures
- Constant air and fluorine monitors provide early detection of process leaks. Airborne materials are routed to a ventilation system consisting of a heater, a roughing filter, and two high-efficiency filters in series. Local exhaust ventilation removes much of the vapor to process scrubbers.
- Off-gas from the cold traps (fluorinator off-gas with most of the uranium hexafluoride removed) passes through a) a 150°C heater, b) a soda-lime trap, c) an activated alumina trap, d) a geometrically safe scrubber, e) a roughing filter and HEPA filter, f) the process area ventilation system.
- Filters and fluoride removal equipment in the cold trap off-gas system are redundant to ensure confinement under upset conditions. The off-gas passes through at least one off-gas system at all times.

- Off-gas scrubbers have high- and low-liquid-level alarms, high- and low-pH alarms, backup solution pumps, and samplers. Solutions are sampled and analyzed periodically to detect accumulation of uranium.
- Vent gas from the cold traps passes through a scrubber, an absorber, and a filter. Aqueous KOH is used to purify this off-gas and prevent release of fluorine, HF, and uranium hexafluoride to the atmosphere.
- Scrubbers have mist eliminators on the vapor discharge lines.
- The fluorinator wall is maintained below 535°C to protect the Monel® reactor
- Connections to the fluorinator from the personnel zones have valving and air purging to confine fluorine. The fluorinator is purged of fluorine upon shutdown.
- The product stream is in a closed system that is not opened during normal operation. Nitrogen is bled into the seal around each rotating shaft that enters the product stream to ensure the exclusion of moist air.
- The pumps that evacuate the loading and sampling manifold are protected from uranium hexafluoride by cold traps and chemical traps

2.16.2 Hole Burned in Fluorinator Vessel (Ref. 5,10)

Causes

- Malfunction of fluorine concentration control system
- Loss of fluidization
- Loss of cooling system or controls

Consequence

- Loss of uranium hexafluoride and fluorine to process area atmosphere

Safety Features

- The fluorinator wall is maintained below 535°C to protect the Monel® reactor
- Constant air and fluorine monitors give early detection of process leaks. Airborne materials

are routed to a ventilation system consisting of a heater, a roughing filter, and two high-efficiency filters in series. Local exhaust ventilation removes much of the vapor to process scrubbers.

- The fluorinator unit is equipped with temperature control and alarms to prevent high heating rates. Pressure control and relief systems are redundant. Both the bed and jacket have high temperature alarms.
- Fluorine and hydrogen produced in this facility are refrigerated to -85°C to reduce their HF content to about 4% and 3%, respectively, by volume.
- An analyzer in the fluorine supply stream monitors the HF concentration

2.16.3 Fluorinator Overpressurization (Ref. 11)

Causes

- Filter pluggage
- High fluorine flow rate

Consequence

- Release of uranium hexafluoride from primary containment

Safety Features

- Valving and flow measuring equipment are in ventilated enclosures
- The fluorinator unit is equipped with temperature controls and alarms to prevent high heating rates. Pressure control and relief systems are redundant. Both the bed and jacket have high temperature alarms.
- The uranium hexafluoride product gas from the fluorinator is filtered through metal filters which have a filtration rating of at least 30 microns. Backup filters are permanently installed so that filtration is maintained even in the event of deterioration of a primary filter element. Automatic, sequenced backflow of the filters provides onstream cleaning.

2.16.4 High HF Concentration in Fluorine Supply (Ref. 5)

Cause

- Malfunction in fluorine production facility

Consequences

- Pressurization of uranium hexafluoride cold traps and loss of uranium hexafluoride to off-gas system
- Loss of moderator control in fluorinator

Safety Features

- Fluorine and hydrogen produced in this facility are refrigerated to -85°C to reduce their HF content to about 4% and 3%, respectively, by volume
- The presence of moderators other than HF is precluded by the closed process system and the use of nonmoderating refrigerant in the cold traps. An analyzer in the fluorine supply stream monitors the HF concentration.
- Vent gas from the cold traps passes through a scrubber, an absorber, and a filter. Aqueous KOH is used to purify this off-gas and prevent release of fluorine, HF, and uranium hexafluoride to the atmosphere.
- Off-gas from the cold traps (fluorinator off-gas with most of the uranium hexafluoride removed) passes through a) a 150°C heater, b) a soda-lime trap, c) an activated alumina trap, d) a geometrically safe scrubber, e) a roughing filter and HPEA filter, f) the process area ventilation system.
- Filters and fluoride removal equipment in the cold trap off-gas system are redundant to ensure confinement under upset conditions. The off-gas passes through at least one off-gas system at all times.
- Off-gas scrubbers have high- and low-liquid-level alarms, high- and low-pH alarms, backup solution pumps, and samplers. Solutions are sampled and analyzed periodically to detect accumulation of uranium.
- Scrubber solutions containing KF are reacted with lime to precipitate calcium fluoride
- Off-gas scrubber solutions are sampled regularly and analyzed for uranium to detect penetration of

uranium fluoride through the hydrofluorinator off-gas filter and to detect escape of uranium hexafluoride from the cold traps.

- The pumps that evacuate the loading and sampling manifolds are protected from uranium hexafluoride by cold traps and chemical traps

2.17 Uranium Hexafluoride Cold Trap and Fluorinator Off-Gas Cleaning

2.17.1 Uranium Hexafluoride Release from Scrubber (Ref. 10)

Causes

- Low caustic concentration in scrubber solution
- Caustic supply to scrubber fails
- Excessive uranium hexafluoride to scrubber
- Mist released from scrubber

Consequence

- Release of uranium hexafluoride to atmosphere

Safety Features

- Off-gas scrubbers have high- and low-liquid-level alarms, high- and low-pH alarms, backup solution pumps, and samplers. Solutions are sampled and analyzed periodically to detect accumulation of uranium.
- Scrubbers have mist eliminators on the vapor discharge lines

2.17.2 Uranium Hexafluoride Release to Vent System (Ref. 10)

Causes

- Cold trap overfilled
- Excessive trap temperature during desublimation cycle

Consequence

- Excessive uranium in scrubber

Safety Features

- Trap weight recorders

- Trap heaters have automatic high-temperature (pressure) cutoffs
- Scrubber solutions containing KF are reacted with lime to precipitate calcium fluoride
- Off-gas scrubber solutions are sampled regularly and analyzed for uranium to detect penetration of uranium fluoride through the hydrofluorinator off-gas filter and to detect escape of uranium hexafluoride from the cold traps.
- Standby traps

2.17.3 High Pressure in Cold Traps (Ref. 1,5)

Causes

- Excessive fluorine or HF present
- Loss of temperature control of cold traps
- Relief valve failure
- Failure of pressure controller
- Failure of temperature controller

Consequences

- Release of uranium hexafluoride
- Rupture of trap

Safety Features

- Vent gas from the cold traps passes through a scrubber, an absorber, and a filter. Aqueous KOH is used to purify this off-gas and prevent release of fluorine, HF, and uranium hexafluoride to the atmosphere.
- Off-gas from the cold traps passes through a) a 150°C heater, b) a soda-lime trap, c) an activated alumina trap, d) a geometrically safe scrubber, e) a roughing filter and a HEPA filter, and f) the process area ventilation exhaust system.
- Filters and fluoride removal equipment in the cold trap off-gas system are redundant to ensure confinement under upset conditions. The off-gas passes through at least one off-gas system at all times.

- The uranium hexafluoride traps are equipped with relief valves which connect to a surge tank to reduce the effect of an abnormal overpressurization. Cold traps are designed to operate safely at the maximum pressure (400 psig) that could be encountered due to the presence of appreciable HF during uranium hexafluoride melting. The traps have pressure monitors and alarms.
- Cold trap heat transfer surfaces are designed to provide a double barrier between the coolant and the uranium hexafluoride. The coolant inventory is monitored to detect leaks before hazardous conditions result.
- Constant air and fluorine monitors provide early detection of process leaks. Airborne materials are routed to a ventilation system consisting of a heater, a roughing filter, and two high efficiency filters in series. Local exhaust ventilation removes much of the vapor to process scrubbers.
- Area ventilation exhaust is scrubbed with potassium carbonate to remove fluorides and fluorine in the event of leakage from process equipment.
- Off-gas scrubbers have high- and low-liquid-level alarms, high and low-pH alarms, backup solution pumps, and samplers. Solutions are sampled and analyzed periodically to detect accumulation of uranium.
- The presence of moderators other than HF is precluded by the closed process system and the use of non-moderating refrigerant in the cold traps. An analyzer in the uranium enrichment is verified by analysis to confirm that the uranium fluoride cylinder is appropriate. Analysis also confirms that HF content is less than or equal to 0.5%, a moderation control for nuclear safety.

2.18 Product Loading and Storage

2.18.1 Failure of a Uranium Hexafluoride Product Cylinder

Causes

- Vessel rupture from impact, e.g. by crane
- Processing line break from high pressure created by failure of the heating system on a process line, pluggage of the line, and subsequent line warming.
- Dropped product cylinder

Consequence

- See Tables 9.4.16-1 and -2 in Reference 5

Safety Features

- Process piping has low-temperature monitors with alarms to warn of potential pluggage
- Uranium fluoride loading and storage areas have criticality monitors, and evacuation alarms, fluoride monitors and alarms
- Fume hoods in the uranium hexafluoride area collect any uranium hexafluoride fumes released during product loading operations. These fumes are directed to a geometrically safe fume scrubber for treatment before being released.
- A pressurized carbon dioxide system permits quick cooling of valves and piping in the event of a uranium hexafluoride leak
- Check valves and safety shutoff valves close automatically to prevent flow reversals
- Constant air and fluorine monitors provide early detection of process leaks. Airborne materials are routed to a ventilation system consisting of a heater, a roughing filter, and two high-efficiency filters in series. Local exhaust ventilation removes much of the vapors to process scrubbers.
- Area ventilation exhaust is scrubbed with potassium carbonate to remove fluorides and fluorine in the event of leakage from process equipment
- Off-gas scrubbers have high- and low-liquid-level alarms, high- and low-pH alarms, backup solution pumps, and samplers. Solutions are sampled and analyzed periodically to detect accumulation of uranium.
- The storage and shipping container for uranium hexafluoride is a Model 48Y uranium hexafluoride cylinder with the following specifications: a) wall thickness is 5/8 inch, b) material of construction is steel, c) service pressure is 200 psig, d) hydrostatic test pressure is 400 psig.
- Product cylinders are held in a horizontal position on a dolly to reduce the potential of cylinders being dropped

2.19 General - UF_6 Production

2.19.1 Criticality Potential in UF_6 Production Facility

Cause

- Fissile uranium accumulation in solid form

Safety Features

- An accountability tank is used to receive uranyl nitrate solution from the solvent extraction facility. Tank contents are sampled and analyzed to determine that the solutions meet specifications
- Analytical equipment for analyzing incoming feed must be capable of reliably detecting alpha activity due to all transuranic elements at 1500 d/m/g of total uranium
- For nuclear safety in systems where uranium can collect and the material can be reflected, the diameter limit is 40 cm
- If the material cannot be reflected, the diameter limit is 47 cm
- The maximum batch size of uranium metal is 312 kg (688 lb)
- Steam pressure in the evaporator heating coils is kept below 80 psig (160°C) to prevent denitration. (There are no nuclear safety limits on 1.6% U-235 mass or concentration in the absence of denitration.)
- Specific gravity and temperature instruments aid in controlling the uranium concentration in the evaporator reboiler
- Limit switches close the steam supply if the steam pressure in the reboiler shell or the bottoms temperature exceed preset values
- Fluorine and hydrogen produced in this facility are refrigerated to -85°C to reduce their HF content to about 4% and 3%, respectively, by volume
- Moderation control is aided by operation above 180°C. If a system malfunction results in denitrator temperature below 180°C, redundant temperature interlock circuits shut down all hydrogenous streams (e.g. feed) entering the unit.
- Moderation control in the reductor and hydrofluorinator depends upon maintaining the bed temperature above 150°C. Alarms sound at 200°C.

Redundant interlocks shut down the flow of feed if the bed temperature drops below 150°C. The beds are fluidized with dry nitrogen at startup and at shutdown to avoid condensation of moisture.

- An analyzer in the fluorine supply stream monitors the HF concentration
- The presence of moderators other than HF is precluded by the closed process system and the use of nonmoderating refrigerant in the cold traps (NFS). An analyzer in the fluorine supply stream monitors the HF concentration.
- Uranium hexafluoride loading and storage areas have criticality monitors, air monitors, and evacuation alarms. Fluoride monitors and alarms.
- Liquid uranium hexafluoride is drained from the cold trap to a Monel® collection tank equipped with a sampler and freezing-point-measuring capability
- Before loadout of purified uranium hexafluoride, the uranium enrichment is verified by analysis to confirm that the uranium hexafluoride cylinder is appropriate. Analysis also confirms that the HF content is less than or equal to 0.5%, a moderation control for nuclear safety.
- The off-gas scrubber has high- and low-liquid-level alarms, a low-pH alarm, a backup solution pump, and a sampler
- Off-gas scrubber solutions are sampled regularly and analyzed for uranium to detect penetration of uranium fluoride through the hydrofluorinator off-gas filter and to detect escape of uranium hexafluoride from the cold traps
- The uranium hexafluoride product gas is filtered as it goes from the fluorinator to the cold traps
- The uranium hexafluoride product gas from the fluorinator is filtered through metal filters which have a filtration rating of at least 30 microns. Backup filters are permanently installed so that filtration is maintained even in the event of deterioration of a primary filter element. Automatic, sequenced blowback of the filters provides on-stream cleaning.
- Excessive particulate filter loading or failure is signaled by pressure differential alarms
- Pressure alarms indicate unsatisfactory pressure drop conditions on the off-gas filters

- The reductor off-gas passes through a cooler and two filters before being exhausted to the atmosphere. The filters are electrically heated to prevent moisture condensation and are vented to the dust collection system.
- The two filters are electrically heated to prevent moisture condensation. They are "blown back" periodically with hot nitrogen to prevent pluggage.
- Low-temperature alarms on the reductor off-gas filters sound at 185°C to warn of filter heater failure
- Low-temperature alarms on the hydrofluorinator off-gas filters sound at 200°C to warn of filter heater failure
- Fluorinator bed material can be removed periodically to prevent buildup of Pu and fission products in the system

2.19.2 Fire

Causes

- Solvent in feed to facility
- Ignition source present
- Pyrophoric oxide powder
- Hydrogen leak

Consequences

- Equipment damage
- Airborne activity
- Loss of process control
- Filter pluggage

Safety Features

- Analytical equipment for analyzing incoming feed must be capable or reliably detecting one part Ru, one part Nb, and 50 parts phosphorus per million parts of total uranium
- The surface of stored uranyl nitrate solutions can be inspected for the presence of floating organic material
- An automatic fire suppression system serves the denitrator area

- A combustible gas detector with an audible alarm is located near the denitrator
- Pyrophoric uranium dioxide is not allowed to come into contact with air
- A flame arrestor on the off-gas stream protects against the flashback of hydrogen
- A flame arrestor on the hydrogen off-gas line from the fluorine plant protects against the flashback of hydrogen
- Cells containing the molten electrolyte are completely enclosed , ventilated, and operated at near-atmospheric pressure. The fluorine generation and cell cleaning areas are separated from other process areas by a fire wall.

2.19.3 Fire in a Stack (Ref. 10)

Cause

- Hydrogen ignition by lightning or static electricity

Consequence

- Damage to HEPA filters

Safety Features

- A flame arrestor on the off-gas stream protects against the flashback of hydrogen
- A flame arrestor on the hydrogen off-gas line from the fluorine plant protects against the flashback of hydrogen
- Hydrogen gas generated in the fluorine facility is diluted with air below its lower of 4% before being released to the atmosphere
- Process stacks are equipped with thermocouples to detect hydrogen fires

2.19.4 Uranyl Nitrate Solution Leaks (Ref. 1,11)

Causes

- Corrosion in valves, pipes, tanks, and pumps
- Damage to piping or tanks from impact or weather

Consequences

- Release of radioactive material from primary containment
- Uranium from process stack (Ref. 11)

Safety Features

- Transfer lines from the solvent extraction facility are protected from weather and from impact by vehicles
- A sump in the storage area collects spilled or leaked solution. A level alarm indicates accumulation of liquid.
- Assurance that loss of material from the evaporator does not result in a significant hazard is provided by the following features: a) a sump system ensures that material is collected in a favorable slab geometry, b) an automatic floor flushing system beneath the evaporators and piping continuously monitors the specific gravity of the flush solution to give an early indication of any gradual leakage to the cell, c) sump liquid level instruments provide prompt detection in the event of a major leak.
- Concentrate lines to the denitrator are Teflon® lined for corrosion protection and insulated with fiberglass
- A collection tank is provided to accumulate equipment decontamination washes for transfer to the waste handling facility

2.19.5 Uranium Hexafluoride Release (Ref. 1,10,11)

Cause

- Leaking valves, containers, or flanges

Consequences

- Inhalation uptake by operating personnel
- Uranium released from process stack (Ref. 11)
- Uranium hexafluoride released to process area (Ref. 10)

Safety Features

- Constant air and fluorine monitors provide early detection of process leaks. Airborne materials are routed to a ventilation system consisting of a heater, a roughing filter, and two high efficiency filters in series. Local exhaust ventilation removes much of the vapor to process scrubbers.
- A portable fume- and dust-collection outlet is provided in the area to remove fumes and dust released during maintenance

- Carbon dioxide is provided on a standby basis so that any uranium hexafluoride leaks can be readily stopped by freezing to permit correction. Dry nitrogen is supplied to purge lines and vessels.
- Off-gas from the cold traps (fluorinator off-gas with most of the uranium hexafluoride removed) passes through: a) a 150°C heater, b) a soda-lime tray, c) an activated alumina trap , d) a geometrically safe scrubber, e) a roughing filter and a HEPA filter, f) the process area ventilation exhaust system.
- Filters and fluoride removal equipment in the cold trap off-gas system are redundant to ensure confinement under upset conditions. The off-gas passes through at least one off-gas system at all times.
- Off-gas scrubbers have high- and low-liquid-level alarms, high- and low pH alarms, backup solution pumps, and samplers. Solutions are sampled and analyzed periodically to detect accumulation of uranium.
- Scrubbers have mist eliminators on the vapor discharge lines
- The product stream is in a closed system that is not opened during normal operation. Nitrogen is bled into the seal around each rotating shaft that enters the product stream to ensure the exclusion of moist air.
- The fluorinator wall is maintained below 535°C to protect the Monel® reactor
- Vent gas from the cold traps passes through a scrubber, an absorber, and a filter. Aqueous potassium hydroxide is used to purify this off-gas and prevent release of fluorine, HF, and uranium hexafluoride to the atmosphere.
- Cold trap heat transfer surfaces are designed to provide a double barrier between the coolant and the uranium hexafluoride. The coolant inventory is monitored to detect leaks before hazardous conditions result.
- Sorbent materials from the absorber traps are handled in isolated systems to preclude release of particulates.

- Liquid uranium hexafluoride is drained from the cold traps to a Monel® collection tank equipped with a sampler and freezing-point measuring capability
- The uranium hexafluoride cold traps are equipped with relief valves which connect to a surge tank to reduce the effect of an abnormal overpressurization. Cold traps are designed to operate safely at the maximum pressure (400 psig) that could be encountered due to the presence of appreciable HF during melting of the uranium hexafluoride. The traps have pressure monitors and alarms.
- Fume hoods in the uranium fluoride area collect any uranium fluoride fumes released during product loading operations. These fumes are directed to a geometrically safe fume scrubber for treatment before being released.
- A pressurized carbon dioxide system permits quick cooling of valves and piping in the event or a uranium fluoride leak
- Uranium hexafluoride loading and storage areas have criticality monitors, air monitors, and evacuation alarms. Fluoride monitors and alarms.
- Check valves and safety shutoff valves close automatically to prevent flow reversals
- The pumps that evacuate the loading and sampling manifolds are protected from uranium hexafluoride by cold traps and chemical traps
- The storage and shipping container for uranium hexafluoride is a Model 48Y cylinder with the following specifications: a) wall thickness 5/8 inch, b) material of construction is steel, c) service pressure is 200 psig, d) hydrostatic test pressure is 400 psig.
- The pressure in a filled uranium hexafluoride cylinder is limited to 75 psia at 200°F (93°C)

2.19.6 Airborne Uranium Oxide (Ref. 11)

Cause 1

- Evaporator eructation

Consequences

- Inhalation of radioactive material
- Personnel contamination

Safety Features

- An accountability tank is used to receive uranyl nitrate solution from the solvent extraction facility. Tank contents are sampled and analyzed to determine that the solutions meet specifications.
- Analytical equipment for analyzing incoming feed must be capable of reliably detecting one part Ru, one part Nb, and 50 parts of phosphorus per million parts of total uranium
- Before evaporation, entrained process solvent is removed by decantation to eliminate a hazard in subsequent process steps. Tributyl phosphate decomposes rapidly when heated with nitrate at temperatures in the range 0 to 160°C.
- Feed storage tanks used as decanters have inlet baffles which maintain smooth blending of incoming solution with stored solution and avoid re-entrainment of organic layers
- The surface of stored uranyl nitrate solutions can be inspected for the presence of floating organic material
- The evaporator feed pump cuts off automatically to avoid inadvertently pumping the evaporator feed tank empty
- Steam pressure in the evaporator heating coils is kept below 80 psig (160°C) to prevent denitration. (There are no nuclear safety limits on 1.6% U-235 mass or concentration in the absence of denitration.)
- Specific gravity and temperature instruments aid in controlling the uranium concentration in the evaporator reboiler
- Limit switches close the steam supply if the steam pressure in the reboiler shell or the bottoms temperature exceed preset values
- The first and second-stage thermosyphon evaporators are equipped with demister pads to remove entrained material from overhead vapors. The inherently stable operation of a thermosyphon evaporator has a low probability of "bumping."
- Sudden pressure surges in the evaporator are relieved through a seal pot

Cause 2

- Uranium oxide spills

Consequence

- Personnel contamination and inhalation of radioactive material.

Safety Features

- Vapors from the continuous denitrator are filtered through a bank of 10-micron sintered stainless steel filters. These filters are blown back with dry air periodically to prevent pluggage from uranium oxide dust.
- Uranium oxide solids handling equipment is vented to a dust collection system with two filters
- A vacuum cleaner system discharges solids into the uranium oxide drumout facility
- A vacuum cleaner system discharges spilled solids to the fluorinator fines system, which also collects fines from the fluorinator product filter.
- A collection tank is provided to accumulate equipment decontamination washes for transfer to the waste handling facility
- Airborne particulates, aerosols, or vaporized process materials resulting from component failure enter the cell atmosphere and are routed to the building ventilation system equipped with a deep-bed fiberglass filter and two HEPA filters in series. Process exhaust ventilation is provided near equipment connections to collect dust and limit spread of contamination.
- Constant air monitors provide continuous, redundant detection of airborne alpha contamination. Equipment which requires routine maintenance or is prone to leakage (e.g., solids feeders, and drain valves) is enclosed in confinement boxes maintained at subatmospheric pressure.
- Exhaust air from dust moving or dust collection systems are monitored for dust density before release to the atmosphere. Blowers are automatically shut down and the air flow is diverted to a parallel filter system in the event of high dust density.
- Powder level measurement in the incoming uranium oxide feed vessel provides continuing protection from powder clogging the system or loss of the powder seals on either side of the reduction area.

Cause 3

- Dust collector failures

Consequence

- Personnel contamination and inhalation of radioactive material

Safety Feature

- Exhaust air from dust moving or dust collection systems are monitored for dust density before release to the atmosphere. Blowers are automatically shut down and the air flow is diverted to a parallel filter system in the event of high dust density.

Cause 4

- Denitrator fume-out

Consequence

- Personnel contamination and inhalation of radioactive material

Safety Features

- Constant air monitors provide continuous, redundant detection of airborne alpha contamination. Equipment which requires routine maintenance or is prone to leakage (e.g. solids feeders, and drain valves) is enclosed in confinement boxes maintained at subatmospheric pressure.

- Local exhaust ventilation near the denitration process equipment removes any fumes or dusts released when either maintenance is performed or the collected dust is removed from the filter dust can.

- Airborne particulates, aerosols, or vaporized process materials resulting from component failure enter the cell atmosphere and are routed to the building ventilation system equipped with a deep-bed fiberglass filter and two HEPA filters in series. Process exhaust ventilation is provided near equipment connections to collect dusts and to limit spread of contamination.

- Denitration fumes are exhausted to a nitric acid fume scrubber and an acid recovery unit. A negative pressure on the denitrator and dust filters ensures proper off-gas flows. The vacuum is controlled automatically.

- Automatic control is provided for the feed rate, the calciner temperature, and the level of solution in the fume scrubber. High and low alarms are provided for the feed flow rate. A high temperature alarm is provided for the calciner temperature. Alarms are also provided for the pressure drop across the filters and the liquid level in the fume scrubber.

2.20 Coconversion Process (UO_2-PuO_2 Production)

2.20.1 Ammonium Nitrate Explosion in Calciner

Causes

- Calciner overheats, or overpressurizes
- Ammonium nitrate decomposes explosively to produce nitrogen, oxygen, and water

Consequences

- Potential breaching of calciner and release of particles to cell air
- Damage to off-gas system

Safety Features

- Automatic shutdown of feed to calciner upon process malfunction
- Pressure relief disc on calciner off-gas filter (disc relieves off-gas directly to the scrubber)
- Monitor for calciner bed temperature with interlock to shut off feed to bed at temperatures below predetermined setpoint (prevents accumulation of ammonium nitrate in the calciner)

2.20.2 Hydrogen Gas Explosion in Process Area

Causes

- Hydrogen concentration exceeds explosive limit (more than 5.7% hydrogen in nitrogen or greater than 4% hydrogen in air) (Ref. 12)
- Leak in hydrogen delivery system
- Ignition source (electrical equipment)

Consequences

- Missiles

- Overpressures below those required to destroy reduction equipment
- Potential release of radioactive material to process area

Safety Features

- Hydrogen detectors and alarms in storage area and cell
- Analytical verification of hydrogen concentration in feed gas
- Use of less than 5.7% hydrogen in nitrogen for reducing gas. The "standard limiting safe mixture" is 94.3% nitrogen-5.7% hydrogen, i.e. this gas is not flammable alone or mixed with air.

2.20.3 Hydrogen Explosion in a Plutonium Nitrate Storage Tank (Ref. 5)

Causes

- Radiolysis of water by alpha radiation
- No air purge of storage tank (purge fails or is diverted)
- Spark from electrical equipment (or another source). (All three are required.)

Consequences

- Tank rupture or warping of slab tank (criticality potential)
- Mist released from tank to cell air (airborne activity)
- Solution spilled to cell floor
- See Tables 9.4.4-1 and -2 in Ref. 5 for estimated radionuclide release values and potential offsite exposures

Safety Features

- Air purge of tank to vessel vent system with low purge flow alarm
- Coprocessing flow sheet dilutes the plutonium with uranium, reducing the radiolysis rate
- Tanks contain no electrical equipment, heaters, or other sources of ignition

- Incident detected by vent header pressure monitor
- Liquid from tank rupture goes to a sump with liquid level instrumentation
- Cell air ventilation system

2.20.4 Process Solution Leak (Ref. 5)

Causes

- Mechanical failure in pump
- Gasket/flange failure on jumper or connector
- Weld failure
- Valve failure

Consequences

- Release to sump
- Airborne activity in cell air

Safety Features

- Sump liquid detector and alarm
- Sump with favorable geometry
- Process area ventilation system
- Visual observation through cell windows

2.20.5 Transfer Errors

Causes

- Operator error and procedural error
- Process problems
- Pluggage in transfer lines causing backpressure or flow

Consequences

- Overflows
- Uncontrolled reactions (e.g. precipitator chemical to wrong tank)

Safety Features

- The nature of this incident makes procedural controls a major safety feature
- Fixed valving and transfer lines (i.e. reduce the "flow anywhere nature" of a reprocessing facility)
- Instrumentation to indicate and alarm significant changes in temperature, specific gravity, radioactivity, or pressure
- Clearly labeled valves
- Dedicated piping

2.20.6 Overflows

Causes

- Overfilling a tank
- Instrument failure
- Eructation
- Operator errors

Consequence

- Spread of contaminated liquid to process cell, sump, ventilation system, or off-gas system

Safety Features

- High-liquid level indicators and alarms
- Sump liquid indicators and alarms
- Activity sensors and alarms
- Procedural controls
- Sump tanks with favorable geometry

2.20.7 Chemical Addition Error

Causes

- Transfer errors
- Leaks
- Operator error (adding wrong chemicals)
- Pluggage (failure to add appropriate feed)
- Instrument failures leading to erroneous chemical addition

Consequences

- Uncontrolled chemical reactions
- Product or material losses
- Contamination or release

Safety Features

- Procedural controls
- Redundant process controls
- Temperature, pressure, and specific gravity sensors

2.20.8 Pressurization of Calciner (Ref. 5,13)

Causes

- Excessive off-gas flow (uncontrolled reaction)
- Flow restriction (pluggage) in off-gas system
- Low off-gas vent header vacuum
- Excessive air flow into calciner
- Pluggage in calciner filter

Consequences

- Contamination forced into off-gas scrubber
- Potential for release of plutonium-containing aerosol to cell air (airborne activity), if disc fails to rupture as designed

Safety Features

- Pressure instruments and pressure monitor on calciner
- Interlock to shut down feed flow to calciner
- Rupture discs on calciner
- Off-gas filter differential pressure monitors and high-Delta-P alarm
- Low vacuum alarm on venturi scrubber
- Differential pressure monitor on scrubber tower
- Filter blowback

2.20.9 Calciner Breached from Internal Corrosion (Ref. 13)

Cause

- Corrosive materials in the calciner

Consequence

- Release to the process cell and cell ventilation system

Safety Features

- Calciner is constructed of corrosion-resistant material
- Calciner operating pressure is near-atmospheric

2.20.10 Calciner Breached from Impact (Ref. 13)

Causes

- Impact by hot-cell crane
- Missiles

Consequence

- Release to process cell and cell ventilation system

Safety Features

- Impact resistant construction
- Administrative controls

2.20.11 Excessive Penetration of Calcine through the Calciner Primary Filter (Ref. 5)

Causes

- Stress
- Corrosion
- Improper mounting of filter

Consequences

- Increased radioactivity in off-gas
- High radioactivity in condenser and off-gas scrubber
- Filter replacement results in releasing airborne radioactivity to the cell

Safety Features

- Dual filters
- Filter Delta-P monitors and alarms
- Plutonium monitor on Venturi scrubber
- Mist eliminator tower designed for nuclear safety
- Filters designed for ease of replacement

2.20.12 Filter Systems Breached (Ref. 13)

Causes

- Maintenance error
- Housing failures
- Vibration

Consequence

- Release of airborne activity to venturi scrubber

Safety Features

- Design of filter housings
- Duel independent filter in series
- Filter differential pressure monitors and alarms

2.20.13 Uncontrolled Reactions

Causes

- Chemical addition errors
- Process control difficulties (i.e. temperature or process controls)
- Personnel or procedural difficulties

Consequences

- Explosion
- Boilover
- Eructation
- Product degradation with related releases or equipment damage
- Toxic vapor release

Safety Features

- Procedural controls
- Instrumentation (process control) on critical equipment
- Dedicated piping

2.20.14 Fire in a Process Cell (Ref. 14)

Causes (Both are Required)

- Flammables present in the processing cell
- Ignition source or spontaneous combustion

Consequences

- Interruption of the general ventilation for alpha monitoring of the stack. For 5 x 10^{-6} curies/cubic meter stack activity, the system activates total closing of the ventilation system with consequent loss of dynamic containment of the building.
- Primary filters could be destroyed

Safety Features

- Fire suppression system (CO_2, Halon)
- Fire detectors in the outlet ventilation duct (sense 5°C/min with an alarm at 50°C change)
- Smoke detectors on the top of the cell (detector type not affected by radiation)
- Automatic signal to control room and opening of the outlet ventilation duct in the cell
- Activity monitor on the stack
- Multiple containment barriers, including a sand filter

2.20.15 Fire Suppression System Failure (Ref. 14)

Causes

- No electrical power or instrument air
- Valves fail in closed position
- Broken feed pipe
- Alarm failure

Consequence

- Fire continues to burn in cell with release to ventilation system

Safety Features

- CO_2/Halon systems
- Manual activation of fire suppression system
- Smoke alarms (emergency power)
- Stack release alarms (emergency power)
- Suppression discharge valves have emergency air air reservoir for operation without instrument air
- Locate suppressant bottles in adjacent room and provide manual release valves

2.20.16 Uranium in Steam Condensate or Cooling Water Returns from the Uranium Oxide Dissolver

Cause

- Leak in heating or cooling coil in the dissolver

Consequence

- Natural uranium released to the water system

Safety Features

- Monitor (colorimeter) for uranium
- Diversion system for contaminated water or secondary loop

2.20.17 Power Failure

Causes

- Natural phenomena (e.g. lightning)
- Switchgear failure in motor control center

Consequence

- Potential release of radioactivity to occupied areas only in the event of other system failures

Safety Features

- Emergency power system with diesel-driven generator and automatic transfer switching

- Emergency electric power should be supplied to a) instruments, alarms, and controls, b) emergency lighting, c) fire detection and suppression system, d) scrubber solution pumps, e) cooling air supply system to the product array, f) ventilation, hood, and off-gas blowers, exhausters, and fans

2.20.18 Hydrogen Explosion in Cold Chemical Area (Ref. 5)

Causes

- Leaking valve, pump, or container in hydrogen supply system
- Hydrogen valving error
- Ignition source necessary
- Hydrogen supplied at concentrations above explosive limit

Consequences

- Damage to equipment
- Injury to personnel

Safety Features

- Hydrogen detectors and alarms
- Building ventilation system
- Use of less than 5.7% hydrogen in nitrogen. A 5.7% hydrogen-94.3% nitrogen mixture is not flammable alone or mixed with air.
- Analytical verification of hydrogen concentration in feed

2.21 Waste Calcination

2.21.1 High Temperature Breach of the Calciner (Ref. 13)

Causes

- Criticality in waste
- Excessive heat generation in waste
- Failure of furnace controls
- Calciner furnace overheats the calcine

Consequence

- Release of radioactive material to the cell and to the canyon ventilation system

Safety Feature

- Calciner wall temperature monitors

2.21.2 Calciner Breached from Internal Corrosion (Ref. 13)

Cause

- Corrosive environment in calciner

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Calciner is constructed from a corrosion resistant material

2.21.3 Calciner Breached from Thermal Shock (Ref. 13)

Causes

- Water sprayed on calciner from breach in service lines
- Feed solution not atomized and contacts calciner walls
- Calciner nozzle pluggage
- Loss of atomizing air
- Feedline breached upstream of nozzle

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Features

- Leak detection
- Temperature controls and cooling
- Pluggage prevention and detection devices

2.21.4 Calciner Breached from Pressurization (Ref. 13,15)

Causes

- Explosion of waste
- Excessive feed rate
- Plugged filters
- Calcine buildup
- Criticality of waste
- Loss of temperature control
- Loss of off-gas blower control

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Features

- Mechanical design of calciner is resistant to internal pressurization
- Pressure monitors
- Vibrators
- Filter blowback

2.21.5 Calciner Breached from Impact (Ref. 13)

Cause

- Impact by hot cell crane, external environment

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Impact resistant and administrative controls

2.21.6 Excessive Penetration of Calcine Through Sintered Metal Filters (Ref. 5)

Cause

- Stress or corrosion

Consequences

- Increased radioactivity to the off-gas system (VOG)
- High radioactivity in condensate and VOG absorber solution
- Filter replacement results in releasing airborne radioactivity to the cell

Safety Feature

- Radiation and pressure instrumentation

2.21.7 Filter Systems Breached (Ref. 13)

Causes

- Maintenance error
- Housing failures
- Pluggage with tearing
- Vibration

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Strengthen filter housings

2.22 In-Can Glass Melting

2.22.1 Melter Breached from Pressurization (Ref. 13)

Causes

- Criticality of waste in canister
- Chemical explosion in canister due to impurities in frit, chemical addition error, and water in canister
- Pressurization via calciner

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Melter resistant to pressurization, pressure relief device

2.22.2 Melter (Can) Breached from Internal Corrosion (Ref. 13)

Cause

- Internal corrosive environment

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Corrosion-resistant can material

2.22.3 Melter Breached from Thermal Shock (Ref. 13)

Causes

- Water sprayed on melter from breach in service lines
- Calciner spray nozzle plugged
- Feed solution not properly atomized

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Pressure checks to detect nozzle pluggage and nozzle cleanout needle

2.22.4 Melter Breached from Impact (Ref. 13)

Causes

- Melter impacted
- Improper crane operation

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Melter is impact resistant

2.22.5 Canister Breached by High Temperature (Ref. 13)

Causes

- Excessive generation of waste heat in canister
- Melter furnace too hot
- Failure of annealing furnace
- Operator error
- Criticality in canister

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Feature

- Melter temperature control

2.22.6 Canister Breached by Thermal Shock (Ref. 13)

Causes

- Thermal shock during cooling process
- Canister suffers thermal shock entering cooling basin

Consequence

- Release of radioactive material to cell, or cooling basin, and to canyon ventilation system

Safety Feature

- Canister material resistant to thermal shock

2.22.7 Spill of Radioactive Waste from Canister (Ref. 13)

Causes

- Canister leaks
- Overfilling canister
- Tipping of canister

Consequence

- Release of radioactive material to cell and to canyon ventilation system

Safety Features

- Glass melt level indicator
- Removable catch pan under melter

2.22.8 Criticality

Causes

- Carbon in the calcine creating a reducing atmosphere with potential for settling metallic components
- Accidental addition of other reducing agents

Consequences

- Glass would likely be expelled from canister into the calciner, possibly rupturing the connection between the units
- Airborne activity discharged through ventilation system to atmosphere
- Sharp, but nonlethal, increase in radiation exposure in adjacent personnel areas. Incident is judged to be very unlikely.

Safety Features

- Analysis of feed samples to calciner
- Nuclear safety control procedures
- Neutron monitors

2.22.9 Pluggage of Line from Calciner to Melter (Ref. 16)

Causes

- Foaming
- Loss of level control
- Bridging
- Calcine accumulation in diverter
- Loss of one or more heating zones in furnace

Consequences

- Minor plugging problems judged to be moderately frequent
- Inadequately filled canister
- Release of airborne activity to ventilation system during unplugging operations

Safety Features

- Voltage and current monitors for each zone of furnace
- Air blow at calciner-canister interface

2.22.10 Release of Airborne Activity to Cell or Ventilation System

Causes

- Pluggage of calciner off-gas system
- Failure of diverter between calciner and canisters
- Normal operational releases during disconnecting of canisters
- Pluggage between calciner and melter
- Criticality incident
- Steam explosion
- Overfill of canister
- Failure to install canister

Consequences

- Essentially all of the airborne material reaching the exhaust ventilation filtration system will be trapped with the possible exception of material generated during a criticality accident or a steam explosion

Safety Features

- Off-gas system monitors
- Calciner pressure monitors
- HEPA filters
- Adequate exhaust ventilation filter system
- Administrative control on removal of accumulated debris
- Cell flush system may enhance the probability of a steam explosion

2.22.11 Steam Explosion (Ref. 17-20)

Causes

- Large spill of molten glass into a shallow depth of water
- Water injection beneath glass surface
- Factors tending to enhance the occurrence of an explosion include: a) low water temperature, b) high glass temperature, c) shallow water depth. Chances of explosion increase as depth increases to a few inches, then decreases as depth becomes greater, d) rust on surface beneath water, e) ionic content in water such as salt, f) forced injection of glass into water.
- Factors tending to deter the occurrence of an explosion include: a) high water temperature, b) temperature of glass near melting range, c) great depth of water, d) soluble oils or wetting agent in water, e) grease or oil on surface beneath water, f) prevention of water from accumulating.

Consequences

- Severe shock wave capable of inflicting considerable damage to equipment and possible structural damage to adjacent walls

Safety Features

- Minimize proximity of water to the melter
- Minimize use of gasketed connections
- Slope flooring to enhance rapid water drainage, and removal to remotely located sump
- Avoidance of water collection pockets
- Stainless steel lining on cell floor
- Drainage provisions in catch pans for glass overflow

2.22.12 Major Glass Spill (Ref. 13,16,17-21)

Causes

- Overfilling of canister
- Pressure buildup in canister caused by pluggage
- Excessive furnace temperature fails canister

- Failure of level detection devices
- Foam-out
- Electrical arcing to canister
- Canister knocked over when moved
- Criticality in canister
- Thermal shock
- Impact from external causes
- Hole in canister from fabrication error or corrosion

Consequences

- Steam explosion possible if water present beneath melter
- Increased personnel exposure during cleanup
- Damage of adjacent equipment
- Fire
- Release of airborne activity to ventilation system

Safety Features

- Redundant and diverse level detection devices
- Automatic shutoff of feed should power loss occur
- Neutron monitor
- Retrievable catch pan beneath canister

2.23 Vitrified High Level Waste Storage

2.23.1 High Activity Level in the Storage Pool Water

Causes

- Release from storage canisters
- Contamination from canisters to water

Consequence

- Minimal radioactivity exposure

Safety Features

- Activity monitors
- Filter-deionizer water purifier
- Pool isolation and drainage capability

2.23.2 Contaminated Canisters

Causes

- Cracks in welds
- Canisters not properly decontaminated

Consequence

- Room and cell air contamination

Safety Features

- Ventilation filter system
- Decontamination facilities
- Activity monitors
- Air locks and controlled air in-leakage

2.23.3 Loss of Cooling Water and Shielding

Causes

- Pool leak
- Loss of heat exchanger/tower cooling
- Power outage

Consequences

- Personnel exposure
- Thermal breach of a canister
- Pool boiling and/or evaporation

Safety Features

- Redundant water supply equipment
- Emergency electrical supply to cooling water pumps
- Liquid level and leak detectors
- Automatic sump pump return to filter-deionizer

2.23.4 Canister Stress Corrosion

Causes

- Internal and external corrosion
- Thermal and chemical environments

Consequence

- Contamination of storage pool

Safety Features

- Water quality control (less than 1 ppm chlorine ion and pH of 9 to 12)
- Contamination monitoring of canister and storage pool
- Weld integrity check

2.23.5 Canisters Raised Above Adequate Shielded Level

Cause

- Operator error

Consequence

- Exposure of personnel

Safety Features

- Mechanical stops and electrical limiters on manipulators

2.23.6 Water Loss from Storage Pool

Cause

- *Overflow of pool by external causes*

Consequence

- Spill of contaminated water

Safety Features

- Level control
- Storage pool isolation
- Emergency water supply
- Leakage collection system
- Sump high-level alarm
- Stainless steel pool liner

2.23.7 Canisters Leak Radioactive Waste

Causes

- Weld failures
- Impact of canisters

Consequence

- Contamination of storage pool

Safety Features

- Leak detection
- Contamination checks and decontamination
- Over-packing of contaminated canisters

2.23.8 Water Leaks into the Canister

Causes

- Breach in canister welds
- Impact during transfers
- Internal pressurization

Consequence

- Potential contamination

Safety Feature

- After decontamination, the canisters are allowed to heat to 100°C to dry. No explosive releases are expected for the slow heating rate.

2.23.9 Fire in the Waste Handling Facility

Causes

- Combustible gases
- Personnel error

Consequence

- Potential release of airborne radioactivity

Safety Features

- Equipment and components, especially safety related equipment, shall be protected from possible proximity fires

- Construction materials shall be fire resistant. Combustible gas detectors, fire detection systems, and audible alarms are used in conjunction with fire suppression systems sufficient to quench the maximum credible fire

2.23.10 Canisters Dropped During Handling

Causes

- Operator error
- Equipment failure

Consequence

- Potential radioactive release or contamination

Safety Features

- Special energy absorbing off-loading pad
- Piping insulated and padded to protect from inadvertent impact

2.23.11 Radioactive Release to the Building Air (Ref. 13)

Causes

- Duct failure
- Filter failure
- Fire
- Exhaust fan failure

Consequence

- Potential release of airborne activity

Safety Features

- Reinforced filter housings
- Activity monitors
- Controlled inleakage
- Backup exhaust fan system

2.23.12 Release of Activity Through Cooling Towers (Ref. 13)

Cause

- Breach of heat exchanger

Consequence

- Activity through tower

Safety Feature

- Activity detectors on heat exchangers, secondary cooling loop, and cooling water

2.23.13 HEPA Filter Failure (Ref. 13)

Cause

- Overpressure, excessive solids or water in vent air, operator error, excessive vibration, corrosive environment

Consequence

- Very small release of airborne particulates

Safety Feature

- Reinforced filter housing, monitors on filters to easily detect release, DOP test

2.24 Solid Waste Processing

2.24.1 Fire in Fuel Hardware Fixation Area

Causes

- Pyrophoric forms of zirconium, such as fines adhering to hulls, ignite spontaneously in air
- Loss of argon blanket in hulls hopper or feeder
- Loss of NaOH solution from fines tank

Consequences

- Release of radioactive contamination
- Airborne activity
- 10% loading of ventilation system prefilter. Estimated releases are given in Table 9.4.9.1 of (Ref. 5)

Safety Features

- Fire detectors
- Argon blanket in hulls hopper and feeder
- NaOH solution in fines tank

- Liquid level indicator in fines tank
- NaOH bath for hulls in dissolver area
- Solid extinguishant
- Small sparks and fires self-extinguish
- Ventilation system filters prevent airborne activity releases

2.24.2 Drum Overflow in Fuel Hardware Fixation Area

Causes

- Operator error
- Valve failure
- Instrument failure

Consequence

- Release of radioactive material from primary containment

Safety Feature

- Operators can observe filling operation and prevent drum from overfilling

2.24.3 Airborne Cement Dust in Grout Mixer Area

Cause

- Spills of dry powders during transfers

Consequence

- Inhalation by operating personnel

Safety Features

- Ventilation system
- Cold chemical containment

2.24.4 Radioactive Contamination in Cement Preparation Area (Cold Area)

Causes

- Air flow reversal from hot area

- Ventilation system failure

Consequences

- Skin contamination of operating personnel
- Inhalation uptakes by operating personnel

Safety Features

- Ventilation system backflow dampers
- Contamination control at hot area entries
- Emergency power to ventilation fans

2.24.5 Excessive Fissile Material in Hulls (Ref. 1)

Cause

- Incomplete removal of fissile material from hulls in dissolver

Consequence

- Criticality potential when hulls are dumped into grout

Safety Features

- Dissolver safety features (monitors for dissolvent acid concentration, specific gravity, and volume) ensure dissolution has occurred
- Hulls are monitored for fissile material either in the dissolving area or in the fixation area

2.24.6 Failure of Contaminated Process Components (Ref. 5)

Causes

- Mechanical failure
- Corrosion, stress, or erosion

Consequences

- Exposure of maintenance personnel
- Tipping of full drum (spill)

Safety Features

- Inplace decontamination capability

2.24.7 Waste Container Failure After Filling (Ref. 5)

Causes

- Defective drum (e.g. seam fails)
- Impact with or by other equipment

Consequence

- Release of radioactive material from primary containment

Safety Features

- Visual observation
- Ventilation
- Drum inspection before use
- Welded drums or burst-resistance specification

2.24.8 Drums Improperly filled (No Cement Added)

Causes

- Communication difficulty
- No dry cement in fines drum from cold area
- No grout in hulls drum from cold area

Consequence

- Waste not immobilized in drum

Safety Features

- Visual observation (facility designed so that operator can see the grout level in the drum)
- Color-coded drums
- Weight-controlled interlock to hulls feeder (to prevent addition to an empty drum)

2.24.9 Fire in Beta-Gamma Waste Facility

Causes

- Spontaneous combustion of combustible waste
- Ignition of waste in incinerator feeder (blowback)
- Pyrophoric fines

Consequences

- Airborne activity
- Release of contamination
- Pluggage of ventilated filters

Safety Features

- Automatic fire detection and suppression, portable extinguishers
- Combustibles minimized in incinerator area
- Fire wall between lag storage area and incinerator
- Double-door incinerator charging magazine
- Degraded solvent storage tank located outside the incinerator facility
- Incinerator cell at subatmospheric pressure
- Emergency power to incinerator off-gas system
- Automatic shutdown of incinerator by low air flow sensors

2.24.10 Airborne Activity in the Beta-Gamma Waste Facility

Causes

- Fire
- Waste sorting operations
- Shredding operations in dry disassembly area
- Incinerator overpressurization
- Incinerator ash packaging operations

Consequences

- Uptake by operating personnel
- Release of radioactive material to ventilation system

Safety Features

- Ventilation system
- Double-door charging magazine on incinerator
- Remote washdown of walls and floors to sumps

2.24.11 Violation of Stack Release Guide

Causes

- Excessive concentrations of key fission products in waste fed to incinerator
- Failure of incinerator off-gas treatment

Consequences

- Excessive release to environment
- Process shutdown

Safety Features

- Radiometric assay of incinerator feed
- Computer-controlled rejection of packages to repackaging facility
- Acid-resistant HEPA filters
- Sand filter
- Scrubber solution pumps and off-gas blowers on emergency power system
- Standby blowers that start automatically

2.24.12 Waste Container Failure (Ref. 5)

Causes

- Weld failure
- Fault in drum
- Corrosion
- Impact with or by other equipment

Consequences

- Release of radioactive material from primary containment
- Contamination of process or storage area

Safety Features

- Inspection and testing of drums before use
- Product container survey (smearing)
- Ventilation system

2.24.13 Power Failure

Causes

- Failure of power supply to building
- Failure in motor control center

Consequences

- Airborne activity (vessel ventilation failure)
- Contamination release (air reversal)

Safety Features

- Automatic incinerator shutdown if air flow is too low
- Backflow dampers on ventilation and off-gas systems
- Spare blowers that start automatically (power failure in a blower)
- Diesel-powered emergency generator
- Emergency power to blowers, scrubber pumps, instruments, and emergency lighting

2.24.14 Criticality Potential in Alpha Waste

Causes

- Transfer error in another facility
- Accumulation of fissile material in incinerator ash, or incinerator off-gas scrubber solutions

Safety Features

- True assay of cleanable noncombustibles
- Radiometric assay of combustible waste
- Scrubber solution filters

2.25 Solidification of Intermediate Level Liquid Waste

2.25.1 Fissile Material in Feed (Ref. 1,5)

Causes

- Transfer error in another facility
- Leaks in another facility

Consequences

- Criticality potential
- Loss of fissile material

Safety Features

- Analysis of feed
- Shielding
- Specific gravity indicator and alarm (detection of transfer error)

2.25.2 High Activity Waste in ILLW System (Ref. 1)

Causes

- Transfer error in another facility
- Leaks in another facility

Consequences

- Unusually high radiation from solidified waste
- Abnormal exposure of workers to radiation from product containers

Safety Features

- Analysis of feed
- Gamma monitors on receipt lines
- Product container monitor
- Decontamination capability
- Shielding

2.25.3 Airborne Activity

Causes

- Leaks in piping, valves, or vessels
- Overflows
- Foam-out from mixer
- Suckback through instrument and sample lines
- Loss of vessel ventilation (power failure)

Consequences

- Worker uptakes
- Releases to ventilation system
- Release to atmosphere, if filter fails

Safety Features

- Antifoaming agent
- Remote operation
- Instruments
- Vessel and cell ventilation
- Process sumps and alarms
- Sample line flush
- Instrument line interfacing
- Emergency power
- Redundant blowers

2.25.4 Overflow (Ref. 1)

Causes

- Transfer error
- Instrument failure
- Pluggage

Consequences

- Release of radioactive material from primary containment
- Airborne activity
- Contamination of equipment and product containers

Safety Features

- Instrument and alarms for high liquid levels
- Container monitoring
- Sumps with alarms and transfer jets
- Visual control of drum filling
- Ventilation
- Clearly identified valves

2.25.5 Overexposure of Personnel to Radiation (Ref. 5)

Causes

- Maintenance and repair operations
- Unusually high radiation from product container (e.g. no grout added to batch, etc.)

Safety Features

- Shielding
- Decontamination capability
- Container monitoring

2.25.6 Mixer Pluggage

Causes

- Mixer motor fails
- Power to mixer fails
- No retardant added, rapid setup

Consequences

- Personnel exposure during repairs
- Overflow

Safety Features

- Retarding agent
- Rapid dumping of mixer contents
- Emergency feed shutdown

2.25.7 Waste Container Failure (Ref. 5)

Causes

- Weld failure
- Fault in drum
- Corrosion
- Impact with or by other equipment

Consequence

- Release of radioactive material from primary containment. Contamination of process or storage area.

Safety Features

- Inspection of drums before use
- Monitors
- Ventilation

2.25.8 Uncontrolled Reaction in Mixer or Product Container

Causes

- Chemical addition error in dry mix added to grout mixer
- Chemical addition error to feed

Consequences

- Foam-out from mixer
- Overpressurization and failure of product container. Release of radioactive material.
- Airborne activity

Safety Features

- Dedicated piping for TBP and dry mix addition
- Clearly identified valves
- Color-coded chemical systems
- Ventilation
- Emergency feed shutdown
- Visual observation and manual override

2.25.9 Power Failure

Cause

- Natural phenomena, equipment failures, fire

Consequences

- Airborne activity (ventilation failure)
- Mixer pluggage

Safety Features

- Diesel-powered emergency generator
- Emergency feed shutdown
- Air-operated valves
- Current monitors

3. SPECIFIC INCIDENTS FOR WASTE SOLIDIFICATION

3.1 Waste Removal and Blending

3.1.1 Filter Fire (Ref. 24,25,27)

Cause

- Accumulation and ignition of organic solvents and their degradation products

Consequences

- Release of airborne radioactivity to environment
- Possible explosion

Safety Features

- Fire-resistant filter, heat detection and suppression system, minimization of combustible materials
- Decanter upstream of HAW evaporator
- Off-gas condenser and knockout pot or demister
- Equipment and instrumentation explosion proof
- Redundant continuous radioactivity monitors and alarms
- Backup off-gas system, parallel HEPA filters
- Sand filter downstream of HEPA
- Administrative control restrictions on tank contents

3.1.2 Overflow of Waste Tank (Ref. 23,25-29)

Causes

- Flooding caused by rain
- Overfill during transfer from canyon
- Overfill from external sources
- Annulus overflow
- Overfill caused by flushing
- Overfill during tank-to-tank transfer
- Overfill by siphoning

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Built-in dip tube bubblers
- Conductivity probe on end of reel tape
- One gamma radiation monitor (Vamp) adjacent to each waste tank
- Administrative controls
- Accountability controls
- Gamma radiation monitors in tank risers
- Dip tubes in tank risers
- Storm water diversion system with automatic diversion feature activated by redundant monitors
- Ultrasonic device to determine tank level used at IDNL
- Independent liquid level measuring device for gross level determination

3.1.3 Waste Tank Explosion (Ref. 7,23-28,34)

Causes

- Hydrogen gas
- Organic vapor
- Ammonia gas
- Organics in combination with sodium nitrate
- Mercuric and silver oxalates
- Silver azides

Consequences

- Filters blown out
- Release of airborne and liquid-borne radioactivity to environment

Safety Features

- Purge air system with fault alarm to prevent the accumulation of hydrogen
- Emergency air compressor
- Spare purge air blower with spark-proof electrical system
- Maintain temperatures of solutions containing concentrated ammonia below 39°C
- Emergency power
- Redundant and continuous hydrogen monitors and alarms
- Storm water diversion system with automatic diversion feature activated by redundant monitors

3.1.4 Overflow of Diversion Box or Pump Pit (Ref. 25)

Causes

- Jumper leak
- Transfer error

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Redundant continuous leak detection instruments and alarms
- Gamma monitors located above diversion system
- Storm water diversion system with automatic diversion feature activated by redundant monitors
- Stainless steel lined cell with collection sump
- Redundant transfer jets in collection sump
- Self-sealing concrete covers over diversion box

3.1.5 Damage from Equipment Dropped During Handling

Causes

- Cable breakage, load slips from hook, operator error

Consequences

- Penetration of process vessels, lines, or waste tank

Safety Features

- Safety latch on crane hook

3.1.6 Pump Tank Explosion (Ref. 24,27,33)

Causes

- Hydrogen gas
- Organic vapor
- Ammonia gas
- Organics in combination with sodium nitrate
- Silver azides

Consequences

- Filters blown out
- Cell covers blown off
- Release of airborne and liquid-borne radioactivity to environment

Safety Features

- Purge air to prevent accumulation of hydrogen
- Emergency air compressor
- Maintain temperature of solutions containing concentrated ammonia below 39°C
- Continuous monitoring of purge air flow rate
- Emergency power on purge air blowers
- Storm water diversion system with automatic diversion feature activated by redundant monitors

3.1.7 Above-Ground Release from Service and Process Lines (Ref. 22)

Causes

- Failed valves or valving errors in lines not normally containing waste such as flush lines
- Procedural error or equipment failure in lines normally containing water

Consequence

- Release of liquid-borne radioactivity to environment

Safety Features

- Gamma monitor located on asphalt pads
- Flush water system pressure higher than process system pressure
- Storm water diversion system with automatic diversion features activated by redundant monitors
- Double containment of flush water lines from process to control valve

3.1.8 Release During Equipment Removal

Causes

- Inadequate enclosure
- Equipment dropped

Consequences

- Release of airborne radioactivity to environment
- Equipment damage

Safety Features

- Procedural control
- Tents and windbreaks
- Special equipment removal facilities for contamination control
- Radiation and air activity detectors

3.1.9 Release from Segregated Water (Ref. 5,24,25,28,29,34)

Causes

- Discharge of evaporator steam condensate from tube bundles
- From evaporator and CTS warming coil leaks
- Leaking heat exchangers

Consequence

- Release of liquid-borne radioactivity to environment

Safety Features

- Cooling water monitors
- Delay basin for segregated water discharge
- Diversion to lined retention basin

3.1.10 Boiling Waste Tank (Ref. 2,7,24-29, 35)

Causes

- Cooling tower failure
- Loss of cooling water
- Natural phenomena

Consequence

- Possible release of airborne radioactivity to environment

Safety Features

- Makeup water for cooling system provided by two wells
- More than two weeks elapsed time until tank boils. This is sufficient time to effect repair.
- Tanks with low heat loads can be used to absorb heat from hotter tanks if circulating pumps function
- Cooling water system flow alarms
- Tank temperature recorded. High temperature alarms installed.
- Reflux condensers on waste tanks.

3.1.11 Airborne Release from Diversion Box During Normal Operations and During Maintenance

Causes

- Procedural violation

Consequences

- Inadequate enclosure

Safety Features

- Sealed concrete covers during normal operation
- Wind breaks when covers are off diversion box
- Administrative controls

3.1.12 Suckback

Causes

- Pressure upset between process vessel and instrumentation

Consequences

- High radiation field in personnel areas
- Contamination of steam supply system

Safety Features

- Procedural control of manual gang valves
- Automatic air blow of gang valves if steam supply fails
- Double containment of gang valves and steam lines from gang valves.

3.1.13 Activity By-Passes Waste Tank Filter (Ref. 26,28,29)

Causes

- Missile penetration of filter
- Inadequately sealed riser openings or filter element
- Fire or explosion
- Wet ventilation exhaust filters

Consequences

- Release of airborne radioactivity to environment

Safety Features

- Continuous radioactivity monitors and alarms
- Parallel HEPA filter - backup off-gas system
- Sand filter downstream of HEPA
- Dehumidifier (heater)

3.1.14 Contamination Spread from Localized Spill (Ref. 23,25)

Causes

- Spill coupled with rain and operating error

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Storm sewer system with automatic diversion equipment activated by redundant activity monitors.

3.1.15 Failure of Seal Between Waste Removal Platform and Tank (Ref. 22)

Causes

- Natural events or impact with heavy objects

Consequences

- Release of airborne radioactivity to environment

Safety Features

- Maintain negative tank pressure

3.1.16 Increased Air Activity in Waste Tanks from Slurrying Activity

Causes

- Agitation

Consequences

- Increased potential for overloading ventilation system

Safety Features

- Upgraded ventilation system (nonspecific)

3.1.17 Tank Damage from Vortex Formation

Causes

- Possible vortex formation with multiple pumps may be additive and result in sufficiently violent action to damage tank

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Pre-testing of mockups

3.1.18 Loss of Electric Power (Ref. 2,5,7,24,27,34)

Causes

- Unscheduled power outage, fault in 115 kv system, lightning tripped process feeder breaker, emergency diesel fails to start, failed guy wire, voltage surge from transformer failure, rain-water shorted switchgear.

Consequences

- Loss of cooling water supply and ventilation

Safety Features

- Emergency diesel backup system
- Auto-restart on critical equipment

3.1.19 Loss of Instrument or Process Air Compressor (Ref. 5,24)

Causes

- Compressor failure
- Air line failure

Consequences

- Failure of pneumatic instrumentation
- Failure of purge air system

Safety Features

- Automatic start of spare compressor
- Emergency portable air compressor
- Low air pressure instrumentation and alarms

3.1.20 Temperature Excursion in Solids Settling Out of Feed Streams (Ref. 24)

Causes

- Radioactive decay heat

Consequences

- Localized flashing

Safety Features

- Administrative controls
- Temperature instrumentation
- Heat load limits

3.1.21 Overstress of Waste Tank Components

Causes

- Possible vibration interaction among pumps may reach critical frequency for tanks

Consequences

- Leaks

Safety Features

- Controlled startup
- Vibration measurements

3.1.22 Potential for High Personnel Exposure During Installation, Removal, and Maintenance of Sludge Pumps

Causes

- Small clearances through riser

Consequences

- Personnel exposure and potential for transport of contamination to environment

Safety Features

- Spray ring for decontamination
- Shielded, leaktight, container into which pump may be pulled for transport
- Streamlined housing and connection design
- Shielded cable
- Remote, shielded decontamination and maintenance facility for slurry pumps

3.1.23 Loss of Tank Ventilation (Ref. 25)

Causes

- Exhaust filter plugs
- Exhaust blower fails

Consequences

- Accumulation of hydrogen to flammable range

Safety Features

- Backup electric power to blowers
- Spare blower automatically starts
- Pressure control system
- Pressure/vacuum device to vent the primary of the tank to the secondary. Secondary vented to a process cell.

3.1.24 Nuclear Excursion in a Waste Tank (Ref. 25)

Causes

- Accumulation of fissile material in sludge

Consequences

- Release of airborne radioactivity to environment

Safety Features

- Periodic isotopic and nuclear reactivity measurements

3.1.25 Failure to Maintain Adequate Spare Tankage (Ref. 35)

Causes

- Violation of Technical Standards

Consequences

- Inability to cope with failure of a waste tank
- Release of liquid-borne radioactivity to environment

3.1.26 Rapid Corrosion of Carbon Steel Tanks

Causes

- Erroneous transfer of acidic wastes into vessel in excess of neutralization capacity

Consequences

- Leakage of high level waste

Safety Features

- Administrative control
- Analysis of material prior to transfer

3.1.27 Vehicle Collision with Surface Equipment

Causes

- Operator error
- Equipment failure

Consequences

- Possible release of liquid-borne radioactivity to environment
- Equipment damage

Safety Features

- Adherence to design standards to minimize probability

3.1.28 Underground Equipment Crushed by Heavy Vehicles

Causes

- Equipment location not identified

Consequences

- Underground release of process liquid

Safety Features

- Minimize lines under roadways
- Use of load spreaders under heavy equipment

- Provide adequate protection for buried lines in immediate areas of tanks, diversion boxes, etc. from heavy equipment loads
- Specify and post bearing capacities near vital equipment

3.1.29 Failure of Support Structure for Tank Sludge Pumps

Causes

- Inadequate design to support installed weight of pumps
- High winds
- Impact from mishandled loads

Consequences

- Possible release of airborne and liquid-borne radioactivity to environment

Safety Features

- Pre-testing of mockups

3.1.30 Opening of Self-Healed Cracks in Tank

Causes

- Vibration, hydraulic interactions, dissolution of caked material

Consequences

- Leakage to tank annulus

Safety Features

- Dehumidified annulus ventilation air
- Periodic annulus inspections
- Annulus alarms
- Availability of pumpout equipment for tank and annular space

3.1.31 Below-Ground Leaks from Waste Tanks (Ref. 22-28,35)

Causes

- Corrosion/erosion

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Secondary containment is monitored for leakage in primary containment

3.2 Evaporation and Salt Solidification

3.2.1 Overflow of Evaporator Cell (Ref. 25)

Causes

- Evaporator overflow through open vent
- Piping error
- Pluggage

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Stainless steel liner in lower portion of cell
- Leak collection sump with alarm
- Overflow line to waste tank
- Gamma monitors located on asphalt pad
- Storm water diversion system with automatic diversion feature activated by redundant monitors

3.2.2 Release During Equipment Removal

Causes

- Inadequate enclosure
- Equipment dropped

Consequences

- Release of airborne radioactivity to environment

Safety Features

- Procedural control
- Tents and windbreaks
- Special equipment removal facilities for contamination control
- Radiation and air activity detectors

3.2.3 Release from Segregated Water (Ref. 5,24,25,28,29,34)

Causes

- Discharge of evaporator steam condensate from tube bundles
- From evaporator and CTS* warming coil leaks
- Leaking heat exchangers

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Cooling water monitors
- Delay basin for segregated water discharge
- Diversion to lined retention basin

3.2.4 Leak Through Evaporator Cell (Ref. 24)

Causes

- Failure of cell liner
- Cracks in cell structural components

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Leak checks of transfer lines
- Leak detectors
- Control of solution transfer volumes
- Visual inspection
- Stainless steel cell liner

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*Concentrate transfer system (i.e. waste transfer system)

3.2.5 Overflow of Overheads Tank (Ref. 24)

Causes

- Operator error

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Tank surrounded by curbing. Enclosed area equipped with a sump. Alarm in sump.

3.2.6 Evaporator Explosion (Ref. 1,5,7,24,34)

Causes

- Red-oil accumulation
- Silver nitride
- Organics in contact with sodium nitrate

Consequences

- Filters blown out
- Cell covers blown off
- Cell cracked
- Release of airborne and liquid-borne radioactivity to environment

Safety Features

- Sample analysis for phosphorus or organic material
- Centrifugal separation to remove organic material
- Concentrators operated at less than 140°C
- Interlocks automatically turn off steam supply if the solution temperature exceeds control limit or if steam pressure exceeds control limit
- Pressure relief valve on steam supply

3.2.7 Chemical Oxidation of Ruthenium to Volatile Ruthenium Tetroxide (Ref. 24)

Causes

- Series of independent operating errors in acid system

Consequences

- Airborne ruthenium concentration

Safety Features

- Store waste in caustic form

3.2.8 Loss of Cooling Water (Ref. 7,24-29)

Causes

- Cooling water header failure
- Spray cooling tower fails
- Air-binding of cooling coils
- Natural phenomena
- Internal explosion

Consequences

- Solutions containing fission products evaporate to dry form

Safety Features

- Dual backup supply systems
- Reflux condensers on waste tanks
- Greater than one week to take corrective action such as pumping to spare tankage coupled with dilution
- Two water supply wells

3.2.9 Loss of Electric Power (Ref. 2,5,7,24,27)

Causes

- Unscheduled outage, fault in system, lightning, emergency diesel fails to start, transformer failure, etc.

Consequences

- Affects cooling water supply and ventilation

Safety Features

- Emergency diesel backup systems
- Auto-restart on critical equipment

3.2.10 Loss of Instrument or Process Compressed Air (Ref. 5,24)

Causes

- Compressor failure
- Air line failure

Consequences

- Failure of pneumatic instrumentation
- Failure of purge air system

Safety Features

- Emergency portable air compressor
- Automatic start of spare compressor
- Low air pressure instrumentation and alarms

3.2.11 Evaporator Eructation (Ref. 24)

Causes

- Operation outside prescribed limits
- Chemical addition error

Consequences

- Release of airborne and liquid-borne radioactivity to environment

Safety Features

- Evaporator pressure and seal pot liquid level instrumentation
- Gas eductor to maintain pressure
- Operating procedures

3.2.12 Evaporator Leak (Ref. 24)

Causes

- Corrosion
- Gasket failure

Consequences

- Leak into stainless steel lined cell

Safety Features

- Cell liner
- Cell equipped with sump, sump level alarm, and automatic pump-out equipment

3.2.13 Major Liquid Release from Waste Tank Riser (Ref. 23,25)

Causes

- Pluggage of inlet riser opening

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Liquid-level detection tubes in concentrate receiving risers to alarm if the waste level builds up
- Gamma radiation detectors at concentrate receiving risers to detect and alarm if spill occurs
- Storm water diversion system with automatic diversion feature activated by redundant monitors

3.2.14 Overflow of CTS* Pit

Causes

- Jumper leak
- Transfer error

Consequences

- Release of liquid-borne radioactivity to environment

* Concentrate transfer system (i.e. waste transfer system)

Safety Features

- Liquid-level surveillance instrumentation in leak collection sump
- Stainless steel sump
- Storm water diversion system with automatic diversion feature activated by redundant monitors

3.2.15 CTS Tank Explosion

Causes

- Hydrogen gas ignition

Consequences

- Filters blown out
- Cell covers blown off
- Release of airborne and liquid-borne radioactivity to environment

Safety Features

- Air purge, monitored for delta-p and temperature, maintained through tank
- Storm water diversion system with automatic diversion feature activated by redundant monitors

3.2.16 Spill from CTS Cleanout Port

Causes

- Catheterization of cleanout ports to remove pluggage

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Procedural control
- Proper bagging techniques
- Continuous radiation monitoring during operation

3.2.17 Erroneous Transfer of Evaporator Materials

Causes

- Valving error, personnel difficulty, piping error, equipment failure, procedural difficulty

Consequences

- Loss of positive control of radioactive materials

Safety Features

- Administrative controls
- All valves clearly identified and labeled

3.2.18 Suckback

Causes

- Pressure upset between process vessel and instrumentation

Consequences

- High radiation field in personnel areas

Safety Features

- Procedural control of manual gang valves
- Automatic air blow of gang valves if steam supply fails
- Double containment of gang valves and steam lines from gang valves

3.2.19 Damage from Equipment Dropped During Handling

Causes

- Cable breakage, load slips from hook, operator error

Consequences

- Penetration of process vessels or lines

Safety Features

- Safety latch on crane hook

3.2.20 Collapse of Salt Cake Storage Tank (Ref. 24,33)

Causes

- Creep

Consequences

- Possible release of liquid-borne radioactivity to environment

Safety Features

- Creep measurements
- Calculations will predict failure
- Fill void with clay if sagging occurs
- Center support structure in tank

3.3 Aluminum Dissolving

3.3.1 Explosion in the Off-Gas System (Ref. 5,6,7)

Causes

- Autocatalytic decomposition of silver and mercury azides plated in condenser – formed from the reaction of ammonia and silver or mercury

Consequences

- Release of airborne radioactivity to canyon ventilation system

Safety Features

- Air purge of off-gas system

3.3.2 Pressurization of the Dissolver (Ref. 1,2,4,5)

Causes

- Loss of cooling to condenser

Consequences

- Discharge of off-gas to cell ventilation

Safety Features

- Interlock to prevent heating without condenser cooling water
- Pressure instrumentation
- Vent dissolver off-gas condenser to canyon

3.3.3 Dissolver Pot Coils Not Submerged During Shutdown

Causes

- Operator error

Consequences

- Loss of ruthenium and other radioactive volatiles to cell atmosphere

Safety Features

- Liquid level instrumentation with fault indicator lights
- Dissolver vented to vessel vent system and subsequently to sand filter

3.3.4 High Liquid Level in Dissolver (Ref. 4)

Causes

- Failure of air lift and level controller; personnel, valving, instrument, alarm, process, procedural, and pump difficulties; piping errors and equipment failure

Consequences

- Overflow of dissolver solution to cell sump

Safety Features

- Liquid level instrumentation with fault indicator lights
- High liquid level alarms

3.4 Centrifugation

3.4.1 Severe Vibration of Centrifuge

Causes

- Inadequate cake dispersion causing lumps to plug centrifuge feed with subsequent imbalance
- Vibration occurs at critical frequencies as centrifuge comes up to speed
- Vibration occurs if feed is stopped and restarted
- Vibration occurs if feed is stopped and bowl contains primarily liquid
- Bearing failure

Consequences

- Reduced safety factor in suspension system

Safety Features

- Automatic braking if vibration is severe
- Vibration frequency and amplitude readout
- Spindle bearing temperature indication

3.4.2 Centrifuge Missile (Ref. 7)

Causes

- Disengagement of centrifuge at high speed

Consequences

- Penetration of adjacent vessel with subsequent loss of material to sump
- Other damage to mechanical and/or electrical systems

Safety Features

- Automatic braking if severe vibration occurs
- Vibration frequency and amplitude readout
- Spindle bearing temperature indication
- Tachometer provided
- Elevation of centrifuge above level of adjacent vessels
- Shielding around centrifuge

3.4.3 Excessive Cake Compaction

Causes

- Operating centrifuge for long period without discharging cake
- Inability to reduce speed at end of compaction cycle
- Change in feed slurry characteristics

Consequences

- Inability to empty centrifuge
- Excessive exposure to personnel during disassembly and disposal

Safety Features

- High pressure sprays

3.4.4 Failure of Centrifuge Suspension System

Causes

- Severe vibration
- Fatigue

Consequences

- Possible shearing of centrifuge feed line

Safety Features

- Automatic braking if vibration is severe
- Vibration frequency and amplitude readout
- Spindle bearing temperature indication

3.4.5 Centrifuge Plow Breaks

Causes

- Plowing at high speeds
- Fatigue
- Plowing of compacted and hard cakes

Consequences

- Centrifuge suspension system would be pushed to its limit. No loss of contents.

Safety Features

- Special sprays to remove sludge from the bowl
- Interlock to prevent plowing at high speed
- Shear pin on plow shaft

3.4.6 Criticality (Ref. 25)

Causes

- Accumulation of fissile materials in sludge

Consequences

- High, localized radiation - some release of fission products to the atmosphere
- Judged to be a very remote occurrence

Safety Features

- Neutron monitor to detect buildup of fissile material

3.5 Sand Filtration

3.5.1 Overflow of Sand Filter

Causes

- Malfunction of backflush timer

Consequences

- Drainage to sump likely

Safety Features

- High liquid level alarm
- Liquid level instrumentation with fault-indicate light

3.5.2 Fire In or Around Sand Filter (Ref. 36)

Causes

- Spillage of anthracite fines and subsequent reaction with strong oxidizing agents

Consequences

- Release of airborne radioactivity to canyon ventilation system

Safety Features

- Periodic cleanup of cell floor and sump

3.5.3 Hydraulic Surge

Causes

- Incorrect sequencing in timing cycle

Consequences

- Possible rupture of piping

Safety Features

- Rupture disc with discharge directed to the sump

3.5.4 Failure of Backflush System to Operate

Causes

- Pluggage of pneumatically controlled valves

Consequences

- High system delta-p, inability to backflush
- Possible system overflow

Safety Features

- High liquid level alarm

3.5.5 Introduction of Nitric Acid into Caustic and Ammonia Bearing Streams

Causes

- Transfer error

Consequences

- Formation of ammonium nitrate with subsequent explosion potential

Safety Features

- Dedicated transfer piping for nitric acid
- Sample analysis

3.5.6 Criticality

Causes

- Accumulation of fissile material in agglomerates in sand filter

Consequences

- High localized radiation - some release of fission products to atmosphere
- Judged to be a very remote occurrence

Safety Features

- Provisions for backflush with nitric acid addition
- Neutron monitor to detect buildup of fissile material

3.6 Sludge-Supernate Separation — General

3.6.1 Transfer Error

Causes

- Valving error
- Personnel difficulties
- Piping error
- Equipment failure
- Procedural deficiency

Consequences

- Transfer to incorrect vessel within shielded canyons, to cell sumps, and to vessels outside shielded area

Safety Features

- Dedicated piping for nitric acid
- Clearly labeled valves and panel boards
- Administrative controls — use-every-time procedures requiring verification by valve number
- Key lock transfer switches
- Remotely controlled valving

3.6.2 Vessel Overflow (Ref. 4,25)

Causes

- Personnel difficulties
- Valving difficulties
- Instrument difficulties (i.e., pluggage of level control)
- Alarm difficulties
- Process difficulties
- Procedural difficulties
- Pump difficulties
- Piping errors
- Equipment failure

Consequences

- Release of liquid-borne radioactivity to cell sump

Safety Features

- Liquid level instrumentation with fault-indicate light
- High liquid level alarm
- Stainless steel lined sumps with alarms
- Test sensor and sump alarm circuits. Separation of sump alarms from sump pump control circuitry.

3.6.3 Transfer Line Pluggage (Ref. 1)

Causes

- Precipitation

Consequences

- Process shutdown
- Some pluggages result in liquid flowing to a sump

Safety Features

- Flow instrumentation
- Differential pressure instrumentation
- Specific gravity instrumentation
- Stainless steel lined sumps with alarms
- Test sensor and sump alarm circuits. Separation of sump alarms from sump pump control circuitry.

3.6.4 Vessel and Line Leakage (Ref. 1,2,5)

Causes

- Corrosion and erosion
- Gasket failure or improper installation
- Stress

Consequences

- Embedded pipe leaks can drain to personnel areas
- Leaks over expansion joints can drain to personnel areas or beneath the building
- Most leaks drain to sumps

Safety Features

- Stainless steel lined sumps with alarms
- Test sensor and sump alarm circuits. Separation of sump alarms from sump pump control circuitry.
- Avoidance of expansion joints where possible
- Transfer record
- Visual observation

3.6.5 Suckback

Causes

- Differential pressure between pneumatic instrumentation and vessel becomes reversed usually due to steam condensation or uncontrolled reaction in the vessel

Consequences

- Very high radiation fields in personnel areas

Safety Features

- Pneumatic-electrical interface in areas normally not occupied by personnel
- Seal pots on cold chemical addition lines
- Gang valves located as high as possible above vessel level
- Procedural control of manual gang valves
- Automatic air blow of gang valves if steam supply fails
- Double containment of gang valves and steam lines from gang valves

3.6.6 *Siphoning*

Causes

- Design error

Consequences

- Transfer of vessel contents to another vessel or to the cell sump

Safety Features

- Siphon break on discharge piping

3.6.7 Coil Failure (Ref. 28,29,34)

Causes

- Corrosion, improper construction materials, vibration

Consequences

- Radioactivity enters cooling water system

Safety Features

- Closed loop cooling on cooling-only coils
- Coil pressure regulator on all heating coils
- Vessel liquid level instrumentation
- Monitoring of each water discharge system

3.6.8 Vessel or Piping Rupture from Impact of Dropped Equipment

Causes

- Crane failure
- Bail failure
- Human error

Consequences

- Solution drains to cell floor and sump
- Cell may overflow in cases where liquid is being fed through the system if flow is not stopped

Safety Features

- Piping protected, where feasible, against dropped loads
- Stainless steel lined sumps
- Sump alarms

3.6.9 Fire

Causes

- Electrical short of agitator or pump motors most probable cause in a sludge-supernate separation
- Ignition of anthracite fines

Consequences

- Usually confined to equipment involved, destroys the insulating material, then self extinguishes
- Negligible effect on the release of radioactivity if ventilation equipment is not involved

Safety Features

- Temperature sensing devices in cells
- Fire suppression system
- Isolation of oxidizable material from heat source
- Periodic inspection and cleaning

3.6.10 Chemical Addition Error

Causes

- Personnel difficulties
- Procedural difficulties
- Valving difficulties
- Process difficulties
- Instrument difficulties

Consequences

- Potential for uncontrolled chemical reaction or nuclear criticality
- Product contamination or loss

Safety Features

- Dedicated piping
- All valves clearly labeled and identified
- Color coding of cold chemical systems

3.6.11 Uncontrolled Chemical Reactions

Causes

- Process control difficulties, such as temperature, chemical addition rates or concentration, entrainment, or unintended accumulation or reactants from pluggage or residuals such as ammonia compounds, hydrogen gas, mercury and/or silver oxalates or oxides, organic vapor
- Procedural difficulties, such as step to preclude the occurrence of the reaction being omitted, or the inadequate technical development to identify the potential
- Alarm and instrument faults, such as instruments not being restored to service following maintenance
- Equipment failures and personnel difficulties

Consequences

- Explosions

Safety Features

- Sampling capability for specified vessels
- High temperature alarms for specified vessels

3.6.12 Total Loss of Cooling Capability (Ref. 2,4,5,7,24-29)

Causes

- Loss of electric power
- Line breakage

Consequences

- Loss of ruthenium and other radioactive volatiles to cell atmosphere
- About 13 days required to reach boiling point if no cooling available and adiabatic heating is assumed

Safety Features

- Maximum resistance design and maximum resistance emergency backup
- Capability for temporary emergency supply of cooling water to canyon vessels

3.6.13 Instrument Line Pluggage

Causes

- Precipitation or settling of process solids
- Corrosion

Consequences

- Results in lack of process monitoring and a reduction in control capability

Safety Features

- Diversity in control instrumentation
- Instrument blow-down facilities

3.6.14 Release During Equipment Removal

Causes

- Failure to adequately remove contents of vessel prior to removal and/or inadequate decontamination
- Improper packaging prior to transport

Consequences

- Intense local radiation
- Contamination of transport equipment, rails or highway

Safety Features

- Procedural controls
- Radiation detectors
- Design carriers for contaminated vessels and equipment

3.6.15 Loss of Electric Power (Ref. 2,5,7,24,27)

Causes

- Lightning
- Electrical equipment failure

Consequences

- Primarily affects cooling water and ventilation systems

Safety Features

- Emergency diesel powered backup systems
- Auto restart on critical equipment
- Double-ended power system

3.6.16 Loss of Instrument or Process Compressed Air (Ref. 5,24)

Causes

- Compressor failure

Consequences

- Loss of pneumatic instrumentation
- Potential backup of radioactivity into air systems

Safety Features

- Automatic start of spare compressor
- Emergency portable air compressor
- Pneumatic valves designed to fail in a safe position

3.6.17 Temperature Excursion in Solids Settling Out of Feed Streams (Ref. 24)

Causes

- Radioactive decay heat

Consequences

- Enhanced corrosion rate

Safety Features

- Temperature controls
- Administrative controls

3.6.18 Leakage Through Cell or Canyon Wall (Ref. 24)

Causes

- Failure of embedded piping
- Seepage through cracks and expansion joints
- Penetration of conduits
- Holes drilled in walls

Consequences

- High, localized radiation or contamination in personnel areas

Safety Features

- Avoidance of expansion joints where possible
- Leak collection and detection at embedded pipe penetrations
- Stainless steel lining on lower 18 inches of walls and floor
- Test sensor and sump alarm circuits - separation of circuitry for alarm and pumpout functions
- Leak collection and detection system beneath canyon floor

3.7 Supernate Decontamination

3.7.1 Cesium Breakthrough of Duolite Column

Causes

- Column overloaded
- Feed analysis error
- Double batching
- Resin degradation
- Column reconditioning error
- Inattention or failure of gamma ray monitor

Consequences

- Contamination of salt cake
- Operation ineffective

Safety Features

- Continuous gamma radiation monitoring
- Flow meter and flow rate control with alarms
- Sampling and analysis of decontaminated supernate

3.7.2 Precipitation in Ion Exchange Column

Causes

- Chemical addition error
- Insufficient regeneration of column

Consequences

- Precipitation of aluminum oxide, aluminum hydroxide, etc. in column and possible column pluggage, overflow of bounce tank, pluggage of samplers, and pluggage of distributors
- Personnel exposure from increased maintenance

Safety Features

- Rinse column after feed cycle - administratively controlled
- Conductivity meter on spent regenerant solution
- High level alarm on bounce tank

3.7.3 Overheating of Zeolite Column

Causes

- Long period of cesium radiation

Consequences

- Produces resin fines or agglomerates causing column pluggage and increased personnel exposure
- Inefficient operation

Safety Features

- Circulated water through the column
- Temperature measuring instrument and alarm
- Gamma monitor

3.7.4 High Temperature in Ion Exchange Column (Ref. 1)

Causes

- Failure of temperature instrument
- Failure to unload column for long period of time with no cooling

Consequences

- Charring of resin - pressurization of ion exchange column
- Damage to equipment
- Activity to vent system and sand filter

Safety Features

- Temperature monitor on the column with alarm

3.7.5 Line and Sampler Pluggage by Resin

Causes

- Leakage during spent resin removal
- Failure of distributor

Consequences

- Overflow
- Increased personnel exposure to unplug lines
- Loss of process control

Safety Features

- Install compressed air to break the pluggage

3.7.6 Uncontrolled Reaction of Resin (Ref. 1,5,6)

Causes

- Decomposition of resin by strong acid (higher than 4M)

Consequences

- Violent reaction, possibly explosion

Safety Features

- No nitric acid in the system
- Dedicated piping for nitric acid used in facility
- Stainless steel lined pump
- Keep resin submerged in liquid
- Temperature monitor on column

3.7.7 Improper Resin Level

Causes

- The swelling and shrinking properties of resin
- Backwash expansion
- Initial overload of column

Consequences

- Backup of resin into feed line, possible pluggage of feed line and samplers
- Personnel exposure from increased maintenance

Safety Features

- Administrative and procedural control

3.8 Ammonia — Carbon Dioxide Recovery

3.8.1 Foaming in Elutriant Recovery Concentration Reboiler

Causes

- Ammonium carbonate - ammonium hydroxide decomposition

Consequences

- Contamination of elutriant recovery system with possible contamination of salt cake
- Pluggage of instrument and vent lines

Safety Features

- Steam stripper
- Feed rate and evaporating rate controls to stripper
- On-line monitor to survey for cesium carryover from stripper to condenser

3.8.2 Pluggage of Elutriant Recovery Condenser

Causes

- Condensation of ammonium carbonate

Consequences

- Ammonia gas leakage
- Contamination of recycle water system

Safety Features

- Downdraft condenser
- Delta-p monitor

3.8.3 Contamination of Cesium Elutriant Makeup with Cesium

Causes

- Entrainment of cesium mist carrier from stripper to downdraft condenser
- High pressure differential across the de-entrainer

Consequences

- Contamination of salt cake
- Contamination of elutriant makeup system

Safety Features

- Install demister at vapor stream exit on stripper
- Monitor pressure drop across the demister and steam pressure drop across the stripper
- Sampling and analysis

3.8.4 Ammonium Compounds

Causes

- Ammonia gas leak
- Cooling water failure on downdraft condenser and/or chilled water failure in scrubber

Consequences

- Vent filter pluggage with ammonium nitrate, possible explosion
- Ammonium nitrate in salt cake, possible explosion
- Deposit and pluggage on ammonium nitrate in process lines

Safety Features

- Dedicated ammonia piping
- Provide separate vent system with chilled water scrubber for cesium ion exchange and elutriant recovery system

3.8.5 Overheating of Concentrator Reboiler (Ref. 5)

Causes

- Malfunction of steam supply cutoff interlock on concentrator pressure

Consequences

- Overconcentration
- Increasing the possibility of pluggage
- Excessive pressure in evaporator

Safety Features

- Temperature, pressure, liquid level and specific gravity instrumentation
- Pressure relief valve on steam supply

3.8.6 Concentrator Overpressurization (Ref. 5)

Causes

- Off-gas flow restriction
- Excessive off-gas flow

Consequences

- Possible contaminated vapor into the cell and cold area
- Contamination of recycle water

Safety Features

- Pressure instrumentation
- Pressure relief through purge condenser

3.8.7 Pluggage of Elutriant Recovery Vent System

Causes

- Loss of condenser water
- Pluggage of condenser

Consequences

- Pressurization of elutriant recovery system

Safety Features

- Heat tracing
- Temperature monitoring of lines

3.9 Recycle Concentration

3.9.1 Accumulation of Ion Exchange Resin in Evaporator (Ref. 1)

Causes

- Failure of the resin column distributor
- Failure of backup screen

Consequences

- Slight pressure surge in concentrator
- Possible fire and explosion

Safety Features

- Backup resin screen

3.9.2 Evaporator Leakage (Ref. 2)

Causes

- Gasket failure
- Corrosion
- Bad weld
- Improper materials or construction

Consequences

- Leak into cell

Safety Features

- Stainless steel lined sump with alarm
- 100% weld inspection
- Corrosion-resistant materials used for evaporator construction

3.9.3 Explosion in Recycle Evaporator (Ref. 2,4,5,6)

Causes

- Mercuric and silver oxalates and silver azides

Consequences

- Release of airborne radioactivity to canyon ventilation system

Safety Features

- High temperature and steam pressure interlocked with steam supply
- Column vented to process vessel vent system and overflow to cell sump

3.10 Supernate Treatment (General)

3.10.1 Transfer Error (Ref. 1)

Causes

- Valving error
- Personnel difficulties
- Piping error
- Equipment failure
- Procedural difficulties
- Miscellaneous

Consequences

- Transfer to incorrect vessel within shielded canyon, to cell sumps, and to vessels outside shielded area.

Safety Features

- Clearly labeled valves
- Procedures requiring verification of valving
- Dedicated piping for nitric acid and ammonia compounds
- Keylock transfer switches
- Remotely controlled valving

3.10.2 Overflow (Ref. 4,5)

Causes

- Personnel difficulties
- Valving error
- Instrument failure
- Alarm ineffectiveness
- Process difficulties
- Procedural error
- Pumping error
- Piping error
- Equipment failure

Consequences

- Release of liquid-borne radioactivity to cell sump

Safety Features

- Liquid level instrumentation and fault indicator lights
- Pressure instrumentation
- All vessels are in secondary containment equipped with sump and alarm
- Test sensor and sump alarm circuits. Separation of sump alarms from sump pump control circuitry.

3.10.3 Transfer Line Pluggage (Ref. 1)

Causes

- Plastic dust covers
- Resin fines

Consequences

- Process shutdown
- Pluggage incidents result in liquid flowing to sumps

3.10.4 Instrument Line Pluggage

Causes

- Corrosion
- Precipitation

Consequences

- Loss of process monitoring

Safety Features

- Diversity in control instrumentation
- Installed instrument blow-down capability

3.10.5 Vessel and Line Leakage (Ref. 1,2,5)

Causes

- Corrosion
- Gasket failure or improper installation
- Stress

Consequences

- About one-half of incident involves significant radioactive release with remainder being steam, water, or clean chemicals.

Safety Features

- Stainless steel lined sumps with alarms
- Avoidance of expansion joints
- All vessels are in secondary containment with sump and alarm
- Test sensor and sump alarm circuits. Separation of sump alarms from sump pump control circuitry.

3.10.6 Suckback

Causes

- Design error

Consequences

- Very high radiation fields in personnel areas

Safety Features

- Siphon break on discharge piping

3.10.7 Coil Failure (Ref. 1,4,5)

Causes

- Corrosion
- Improper materials
- Rupture
- Pluggage

Consequences

- Radioactivity enters cooling water system

Safety Features

- Closed loop cooling, coil pressure regulator on all steam coils, and vessel liquid indicators
- Vessel design
- Monitoring of water discharge systems

3.10.8 Rupture by Externally Induced Impact

Causes

- Explosion
- Natural phenomena
- Fire
- Impact by heavy equipment

Consequences

- The contents of vessel could be lost to cell floor and sump.

Safety Features

- Piping protected
- Stainless steel lined sumps
- Sump alarm

3.10.9 Fire

Causes

- Electric short
- Welding
- Process heat
- Resin ignition

Consequences

- Release of airborne radioactivity to canyon ventilation system

Safety Features

- Temperature sensing device in cells
- Isolation of oxidizable materials from heat sources
- Periodic inspection and cleaning by dilute caustic solution
- Fire suppression system

3.10.10 Chemical Addition Error

Causes

- Personnel difficulties
- Procedural difficulties
- Valving error
- Process difficulties
- Instrument failure

Consequences

- Product contamination or loss
- Resin damage, fire and explosion

Safety Features

- Dedicated piping for nitric acid
- All valves clearly labeled and identified
- Color coding of cold chemical systems

3.10.11 Uncontrolled Chemical Reaction (Ref. 1,4,5)

Causes

- Process control difficulties
- Procedural difficulties
- Alarm and instrument difficulties
- Equipment failure
- Personnel difficulties

Consequences

- Explosion, eructation, foaming, boilover, off gassing, and undesirable high temperature

Safety Features

- Sampling capability for specified vessels
- High temperature alarms for specified vessels
- All equipment in secondary containment equipped with sump and alarm
- All tanks and evaporators have liquid level detector and alarm
- Reboilers have antifoam addition line

3.10.12 Total Loss of Cooling Capability (Ref. 2,4,5)

Causes

- Natural phenomena

Consequences

- High airborne activity release to ventilation system

Safety Features

- Maximum resistance design and maximum resistance emergency cooling backup system

3.10.13 Release During Equipment Removal (Ref. 5)

Causes

- Failure to remove contents prior to removal and/or inadequate decontamination

Consequences

- Intense local contamination

Safety Features

- Procedural control
- Radiation detector

3.10.14 Loss of Electric Power (Ref. 2,5)

Causes

- Unscheduled outage, fault in system, lightning, emergency diesel fails to start, transformer failure

Consequences

- Primarily affects cooling water and ventilation

Safety Features

- Emergency diesel-powered backup system
- Auto restart on critical equipment
- System automatically shut down
- Double-ended power system

3.10.15 Loss of Instrument Air (Ref. 5)

Causes

- Power failure
- Mechanical failure
- Operational error

Consequences

- Increased potential for radioactive release
- Loss of pneumatic instrumentation

Safety Features

- Automatic start of spare compressor
- Emergency portable air compressor
- Pneumatic valves designed to fail in a safe position

3.10.16 Secondary Containment Leakage

Causes

- Failure of embedded piping
- Cracks and expansion joints
- Holes drilled in wall
- Penetration of conduits

Consequences

- High localized radiation or personnel area contamination

Safety Features

- Avoidance of expansion joints if possible
- Leak collection and detection system beneath the canyon floor
- Leak collection and detection at embedded pipe penetration
- Stainless steel lining of cells, canyon floor, and lower 18 inches of walls
- Sumps with alarms

3.10.17 Criticality

Causes

- Accumulation of fissile material (Pu) in ion exchange column and cesium concentrator

Consequences

- Nuclear excursion

Safety Features

- Sampling and analysis of cesium ion exchange feed
- Periodic isotopic and nuclear reactivity measurement
- Neutron monitor

3.10.18 Suckback

Causes

- Design error

Consequences

- Erroneous transfer of liquid-borne radioactivity to unintended location

Safety Features

- Siphon break on discharge piping

3.11 Calcining

3.11.1 High Temperature Breach of the Calciner (Ref. 13)

Causes

- Lack of liquid feed to calciner (nozzle pluggage)
- Excessive heat generation in waste
- Failure of furnace controls results in overheating calciner

Consequences

- Release of calcine to cell ventilation filtration system

Safety Features

- Calciner wall temperatures measured and controlled
- Temperature of waste input stream monitored
- Current, voltage, and coolant flow are monitored for the calciner heaters with automatic system shutdown should malfunction occur
- High temperature shutoffs provided
- Sloped surfaces of cone (60 degrees from horizontal) reduce calcine accumulation on chamber surfaces

3.11.2 Calciner Breached from Internal Corrosion (Ref. 13)

Causes

- Corrosive environment in calciner

Consequences

- Release of calcine to cell ventilation filtration system

Safety Features

- Calciner constructed from corrosion-resistant material such as Incoloy 800H* or Hastelloy C** to minimize corrosion
- Calciner wall temperatures are measured and controlled

3.11.3 Calciner Breached from Thermal Shock (Ref. 13)

Causes

- Water sprayed on calciner from break in service lines
- Feed solution not atomized and contacts calciner walls
- Calciner nozzle pluggage
- Break in feed line before nozzle

Consequences

- Release of calcine to cell ventilation filtration system

Safety Features

- Temperature instrumentation and controls on cooling water flow to induction heater coil
- Differential pressure measurement across feed nozzle
- Remotely operated cleanout needle for mix nozzle

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* Registered trademark of Huntington Alloys, Inc.
** Registered trademark of Cabot Corp.

3.11.4 Calciner Breached from Pressurization (Ref. 1,13,15)

Causes

- Explosion of waste
- Excessive feed rate
- Plugged filters
- Filter blowback valve for one or more filter banks sticks in open position
- Calcine buildup
- Loss of off-gas blower or controls

Consequences

- Possible damage to other equipment in cell
- Release of calcine to cell ventilation filtration system

Safety Features

- Design resistance to pressurization
- Pressure monitors with shutdown interlocks for high calciner pressure
- Pressure relief device, such as seal pot, provided
- Filter blowback sequenced to avoid pressurizing calciner
- Off-gas blower spare

3.11.5 Calciner Breached from Impact (Ref. 13)

Causes

- Impact by crane or dropped equipment
- External causes such as aircraft crash, glass melter steam explosion, extreme natural phenomena

Consequences

- Release of calcine to cell ventilation filtration system
- Release of calcine to external environment from aircraft crash or extreme natural phenomena

Safety Features

- Design: impact resistance
- Administrative and procedural controls

3.11.6 By-pass or Failure of Sintered Metal Filters (Ref. 1,5)

Causes

- Improper filter replacement
- Stress, corrosion, or improper fabrication

Consequences

- Increased radioactivity and particulates to calciner off-gas system
- Activity release to cell if filter replacement required

Safety Features

- Delta-p instrumentation
- On-line particulate analyzer
- Off-gas system designed to handle total filter failure:
  - Venturi scrubbers remove radioactive dust and ruthenium followed by a cyclone and a mist separator
  - Monitors and detectors indicate input off-gas pressure and temperature and liquid level in the sump
  - Sump liquid level detectors are provided for the Venturi scrubber, the mist separator, and the scrubber liquid tank
  - High and low liquid level alarms are provided for the scrubber liquid tank
  - High temperature alarm is provided for the scrubber liquid tank
  - Remaining ruthenium and dust is removed
  - HEPA filters are used for final cleanup prior to gas entering the atmosphere through the sand filter

- Silica gel bed off-gas is monitored for activity level. Bed regeneration or filter replacement is accomplished when activity alarms indicate preset activity levels.
- Pressure drop is monitored across the HEPA and sand filters

3.11.7 HEPA Filter System Breached (Ref. 5,13)

Causes

- Maintenance error
- Housing failure
- Pluggage with tearing
- Vibration
- Hydrogen explosion
- Fire

Consequences

- Release of airborne activity to the sand filter and possibly to the environment

Safety Features

- Sequential filter units
- Sand filter
- DOP testing
- Fire-resistant filter housings
- Administrative control

3.11.8 Energetic Airborne Release (Ref. 5,6)

Causes

- Fire
- Explosion

Consequences

- Release of calcine to cell ventilation filtration system
- Radioactive ruthenium released
- Possible damage to glass melter and other equipment in cell

Safety Features

- Calciner wall temperatures measured and controlled
- High temperature shutoffs provided
- Temperature of waste input stream monitored
- Current, voltage, and coolant flow are monitored for the calciner heaters with automatic shutdown should malfunction occur

3.11.9 High Ruthenium Adsorber Bed Temperature (Ref. 5)

Causes

- Excessive melter temperature

Consequences

- Increased ruthenium release

Safety Features

- Temperature instrumentation and alarm
- Gamma monitor with alarm downstream of adsorber

3.11.10 Increased Volatilization of Ruthenium Tetroxide and Localized Ruthenium Dioxide Deposition (Ref. 1)

Causes

- Calcination temperature drops due to controller failure
- Excessive melter temperature

Consequences

- 10 to 50-fold increase in volatilization of ruthenium with resultant airborne release to canyon ventilation system
- Potential for plateout on cold surfaces of off-gas system

Safety Features

- Current and voltage are monitored for the calciner heaters with automatic system shutdown should malfunction occur
- Calciner wall temperatures are measured and controlled

3.11.11 Excessive Solvent Oxidation in Calciner

Causes

- Organic present in calciner feed

Consequences

- Slight increase in heat load in calciner

Safety Features

- Analysis of calciner feed

3.11.12 Abnormal Nitrate and/or Water in Calcine (Ref. 1)

Causes

- Calciner operated at subnormal temperature
- Scale buildup on calciner wall reducing heat transfer
- Excessive feed rate
- Inadequate atomization

Consequences

- Reduced melting rate, processing problems in calciner
- Potential pluggage of calciner cone and transition pipe to melter

Safety Features

- Calciner wall temperatures measured and controlled
- High temperature shutoffs provided
- Temperature of waste input stream monitored
- Current, voltage, and coolant flow are monitored for the calciner heaters with automatic shutdown should malfunction occur

3.12 Continuous Glass Melting

3.12.1 Steam Explosion (Ref. 17-20)

Causes

- Spillage of molten glass in considerable quantity into a shallow depth of water
- Water injection beneath glass surface
- Factors tending to enhance the occurrence of an explosion include:
  - Low water temperature
  - High glass temperature
  - Shallow water depth. Probability increases as depth increases to a few inches, then decreases as depth becomes greater.
  - Rust on surface beneath water
  - Ionic content in water such as salt
  - Forced injection of glass into water
- Factors tending to deter the occurrence of an explosion include:
  - High water temperature
  - Temperature of glass near melting range
  - Great depth of water
  - Soluble oils or wetting agent in water
  - Grease or oil on surface beneath water
  - Prevention of water from accumulating

Consequences

- Severe shock wave capable of inflicting considerable damage to equipment and possible structural damage to adjacent walls

Safety Features

- Minimize proximity of water to the melter
- Minimize use of gasketed water connections
- Sloped flooring to enhance rapid water drainage and removal to remotely located sump
- Avoidance of water collection "pockets"
- Stainless steel lining on cell floor

- Drainage provision in catch pans for glass overflow
- Two dump canisters with total volume greater than that of the melter and with shroud to protect against entrance of water
- Use of air cooling for electrodes
- Use of air cooling for melter vessel
- Engineered controls for minimizing glass spills such as level and weight control

3.12.2 Refractory Collapse or Spalling (Ref. 37)

Causes

- Accelerated by-passage of current through refractory. Higher resistivity glass causes large fraction of current to pass through refractory. Also location of electrodes too close to refractory wall.
- Fast heat-up rates
- Thermal shock
- Corrosion of refractory
- Voids in refractory, irregular refractory surface finish, wide joints between refractory blocks, excessive number of joints

Consequences

- Weakening of melter wall with possible penetration and spill of glass
- Shortening of melter life with subsequent increase in personnel exposure for replacement
- Possible accumulation of a refractory sludge in the bottom of melter making decommissioning more difficult
- Pluggage of throat and pour spout possible

Safety Features

- Strategically placed thermocouples on melter outer surface to detect erosion or corrosion of liner, especially in throat area
- Low glass velocities

- Redundancy in power supply to reduce thermal shock from repeated recoveries from loss of power
- Avoidance of startup using liquid sodium hydroxide for normal operation
- Refractory specifications include use of void-free and dense refractory, special block finishes involving diamond truing and grinding, joints made as thin as possible, and optimized block size
- Use of sodium hydroxide if glass resistivity becomes high
- Maximum voltage less than 300 to reduce amount of current carried by refractory
- Water cooled steel shell provides secondary jacket for glass containment so that failure of refractory will not result in loss of glass
- Cylindrical design minimizes probability of refractory collapse

3.12.3 Electrical Shorting (Ref. 37)

Causes

- Glass level falls below electrodes while power is on, e.g., during deliberate draining or if bottom freeze plug ruptures
- Arcing from electrode of melter wall
- Arcing through accumulated dust between bus bars
- Sagging of slant heaters and contact with refractory
- Condensation on outer surface of melter
- Water spraying onto electrical connections
- Electrode falls into tank
- Precipitation of refractory materials as a result of addition of reducing agent

Consequences

- Severe damage to electrode
- Penetration of melter shell with subsequent glass spill

- Shock hazard to personnel
- Fire

Safety Features

- Avoid addition of reducing agents to glass
- Grounding of melter shell and floating of electrodes
- Use of insulated power cables rather than bus bars
- Electrical isolation of instruments
- Use of vertical rather than slant electrodes
- Use of fixed resistance heater in pour spout rather than retractable electrode
- Avoidance of liquid caustic startup during normal operation
- Possible use of microwave heating for startup and glass melting
- Monitoring of ground circuit on melter shell for possible detection or arcing

3.12.4 Major Glass Spill (Ref. 13,16,21)

Causes

- Failure of bottom drain system
- Overfilling of canister
- Overpressurizing melter because of pluggage
- Failure of level detection devices
- Foam-out
- Electrical arcing to shell
- Canister knocked over when moved
- Corrosion of melter shell
- Failure of tilt mechanism
- Impact from external causes
- Steam explosion from injection of water beneath glass

Consequences

- Steam explosion possible if water present beneath melter
- Increased personnel exposure during cleanup
- Damage to adjacent equipment
- Fire
- Release of airborne activity to ventilation system

Safety Features

- Top entering electrodes
- External level detection device such as sonic instrument
- Fail-safe tilt mechanism such that power loss will result in melter returning to vertical position
- Automatic shutoff of feed should power loss or pressurization occur
- Retrievable catch pan beneath melter and canister
- Dump canisters beneath bottom freeze plug. Combined volume of dump canisters should be larger than melter volume.
- No uncontained penetration through refractory or containment shell below melt line
- Water-cooled containment shell as secondary barrier to penetration of glass

3.12.5 Criticality

Causes

- Carbon (from sand filter) in the melter creating a reducing atmosphere with potential for settling fissile metals. Addition of silicon metal causes reducing atmosphere.
- General sludge buildup, fissile material in sludge

Consequences

- Glass would likely be expelled from melter into the calciner, possibly rupturing the melter
- Airborne activity discharged through ventilation system to atmosphere
- Sharp, but non-lethal, increase in radiation exposure in adjacent personnel areas
- Incident is judged to be very unlikely

Safety Features

- Analysis of calciner feed
- Nuclear safety control procedures
- Neutron monitor
- High solubility of uranium and plutonium in glass

3.12.6 Pluggage (Ref. 16,37,38)

Causes

- Addition of reducing agent with subsequent precipitation
- High resistivity of glass forces current flow through refractory with possible freezing of glass in melter
- Loss of power or poor power control
- High aluminum in sludge increases glass viscosity
- Foaming
- Loss of glass melt level control
- Spinel crystal formation
- Entrainment of sludge in pour spout
- Loss of electric power - especially to riser
- Faulty ratio of frit to sludge
- Excessive cold cap depth

Consequences

- Minor pluggage problems judged to be very frequent
- Loss of negative pressure with resultant release of activity to exhaust ventilation system
- Loss of level controller
- Loss of function of bottom freeze valve
- Inability to pour into glasstainer
- Eructation into calciner

Safety Features

- Process control
- Redundant compressed air and electrical power supplies
- Level control devices with backup thermocouple level sensors
- Use of instrumentation external to melter where possible
- Alarms to indicate power loss, compressed air loss, low vacuum, instrument faults
- Use of current control for electrodes to maintain uniform conditions
- Aluminum dissolving
- Primary firing, avoidance of DC currents
- Redundant compressed air supply for electrode cooling
- Control of melt temperature
- Fixed, rather than retractable electrodes
- Microwave heating

3.12.7 Release of Airborne Activity to Cell or Ventilation System (Ref. 13,21)

Causes

- Pluggage of calciner off-gas system
- Failure of flexible connection between calciner and melter

- Pluggage between calciner and melter - possibly from excessive foaming
- Failure of bottom drain system
- Arcing to melter shell with subsequent spill
- Criticality accident
- Overfill of canister
- Canister is knocked over
- Melter shell corrosion
- Steam explosion
- Failure of tilt mechanism

Consequences

- Essentially all of the airborne material will be trapped by the exhaust filtration system with the possible exception of a criticality accident or a steam explosion

Safety Features

- Adequate canyon exhaust filtration system
- Top entering electrodes
- Administrative control on removal of accumulated debris
- Cell flush system designed to prevent splashing of water on hot equipment and to prevent accumulation of water on floor
- External level detection device such as sonic instrument
- Fail-safe tilt mechanism such that power loss will result in melter returning to vertical position
- Automatic shutoff of feed should power loss or pressurization occur
- Retrievable catch pan beneath melter and canister
- Dump canister beneath bottom freeze plug. Combined volumes of dump canisters should be larger than melter volume.
- No uncontained penetration through refractory or containment shell below melt line
- Water-cooled steel containment shell as secondary barrier to penetration of glass

3.13 Mechanical Cell

3.13.1 Failure of High Level Waste Canister (Ref. 5)

Causes

- End cap failure
- Closure weld failure
- Circumferential or longitudinal crack
- Catastrophic failure

Consequences

- Release to the sand filter

Safety Features

- Radiation monitors for airborne contamination
- Weld inspection and testing
- Q/A constructed second container

3.14 Sludge Treatment

3.14.1 Transfer Error

Causes

- Valving error
- Personnel difficulties
- Piping error
- Equipment failure
- Procedural deficiency

Consequences

- Transfer errors are to incorrect vessel within shielded canyons, to cell sumps, and to vessels outside shielded area

Safety Features

- Dedicated piping for nitric acid
- Clearly labeled valves and panel boards
- Administrative controls — use-every-time procedures requiring verification by valve number
- Key lock transfer switches
- Remotely controlled valving

3.14.2 Vessel Overflow (Ref. 4,25)

Causes

- Personnel difficulties
- Valving difficulties
- Instrument difficulties (i.e., pluggage of level control)
- Alarm difficulties
- Process difficulties
- Procedural difficulties
- Pump difficulties
- Piping errors
- Equipment failure

Consequences

- Release of liquid-borne radioactivity to cell sump

Safety Features

- Liquid level instrumentation with fault-indicate light
- High liquid level alarm
- Stainless steel lined sumps with alarms
- Test sensor and sump alarm circuits. Separation of sump alarms from sump pump control circuitry.

3.14.3 Transfer Line Pluggage (Ref. 1)

Causes

- Precipitation

Consequences

- Process shutdown
- Some pluggages result in liquid flowing to a sump

Safety Features

- Flow instrumentation
- Differential pressure instrumentation
- Specific gravity instrumentation
- Stainless steel lined sumps with alarms
- Test sensor and sump alarm circuits. Separation of sump alarms from sump pump control circuitry.
- Permanently installed sump and instrument blow-down capability

3.14.4 Vessel and Line Leakage (Ref. 1,5)

Causes

- Corrosion and erosion
- Gasket failure or improper installation
- Stress

Consequences

- Embedded pipe leaks can drain to personnel areas
- Leaks over expansion joints can drain to personnel areas or beneath building
- Most leaks drain to sumps

Safety Features

- Stainless steel lined sumps with alarms
- Test sensor and sump alarm circuitry. Separation of sump alarms from sump pump control circuitry.
- Avoidance of expansion joints where possible
- Transfer record
- Visual observation

3.14.5 Suckback

Causes

- Differential pressure between pneumatic instrumentation

Consequences

- Very high radiation fields in personnel areas

Safety Features

- Pneumatic-electrical interface in areas normally not occupied by personnel
- Seal pots on cold chemical addition lines
- Gang valves located as high as possible above vessel level
- Procedural control of manual gang valves
- Automatic air blow of gang valves if steam supply fails
- Double containment of gang valves and steam lines from gang valves

3.14.6 Siphoning

Causes

- Design error

Consequences

- Transfer of vessel contents to another vessel or to the cell sump

Safety Features

- Siphon break on discharge piping

3.14.7 Coil Failure (Ref. 5,28,29,34)

Causes

- Corrosion, improper construction materials, vibration

Consequences

- Activity in cooling water returns

Safety Features

- Closed loop cooling on cooling-only coils
- Coil pressure regulator on all heating coils
- Monitoring of each water discharge system
- Vessel liquid level instrumentation

3.14.8 Vessel or Piping Rupture from Impact of Dropped Equipment (Ref. 7)

Causes

- Crane failure
- Bail failure
- Human error

Consequences

- Solution drains to cell floor and sump
- Cell may overflow in cases where liquid is being fed through the system if flow is not stopped

Safety Features

- Piping protected, where feasible, against dropped loads
- Stainless steel lined sumps
- Sump alarms

3.14.9 Fire

Causes

- Electrical short of agitator or pump motors most probable cause

Consequences

- Usually confined to equipment involved, destroys the insulating material, then self-extinguishes
- Negligible effect on the release of radioactivity if ventilation equipment is not involved

Safety Features

- Temperature sensing devices in the cells
- Fire suppression system
- Isolation of oxidizable material from heat source
- Periodic inspection and cleaning

3.14.10 Chemical Addition Error

Causes

- Personnel difficulties
- Procedural difficulties
- Valving difficulties
- Process difficulties
- Instrument difficulties

Consequences

- Potential for uncontrolled chemical reaction or nuclear criticality

Safety Features

- Dedicated piping for nitric acid
- All valves clearly labeled and identified
- Color coding on cold chemical systems

3.14.11 Uncontrolled Chemical Reactions

Causes

- Process control difficulties, such as temperature, chemical addition rates or concentration, entrainment, or unintended accumulation or reactants from pluggage or residuals such as ammonia compounds, hydrogen gas, mercury and/or silver oxalates or oxides, organic vapor
- Procedural difficulties, such as steps to preclude the occurrence of the reaction being omitted, or inadequate technical development to identify the potential
- Alarm and instrument faults, such as instruments not being restored to service following maintenance
- Equipment failures and personnel difficulties

Consequences

- Explosions
- Eructations

Safety Features

- Sampling capability for specified vessels
- High temperature alarms for specified vessels

3.14.12 Total Loss of Cooling Capability (Ref. 2,4,5,7,24-29)

Causes

- Loss of electrical power
- Line breakage

Consequences

- Loss of ruthenium and other radioactive volatiles to cell atmosphere

Safety Features

- Maximum resistance design and maximum resistance emergency backup
- Capability for temporary emergency supply of cooling water to canyon vessels

3.14.13 Instrument Line Pluggage

Causes

- Precipitation or settling of process solids
- Corrosion

Consequences

- Results in lack of process monitoring and a reduction in control capability

Safety Features

- Diversity in control instrumentation
- Instrument blow-down facilities

3.14.14 Release During Equipment Removal

Causes

- Failure to adequately remove contents of vessel prior to removal and/or inadequate decontamination
- Improper packaging prior to transport

Consequences

- Intense local radiation
- Contamination of transport equipment, rails or highway

Safety Features

- Design carriers for contaminated vessels and equipment
- Procedural controls
- Radiation detectors

3.14.15 Loss of Electric Power (Ref. 2,5,7,24,27)

Causes

- Transformer failure
- Lightning
- Emergency diesel fails to start

Consequences

- Primarily affects cooling water and ventilation systems

Safety Features

- Emergency diesel-powered backup systems
- Auto-restart on critical equipment
- Double-ended power system

3.14.16 Loss of Instrument or Process Compressed Air (Ref. 5,24)

Causes

- Compressor failure

Consequences

- Loss of pneumatic instrumentation
- Potential backup of radioactivity into air systems

Safety Features

- Automatic start of spare compressor
- Emergency portable air compressor
- Pneumatic valves designed to fail in safe position

3.14.17 Temperature Excursion in Solids Settling Out of Feed Streams (Ref. 24)

Causes

- Radioactive decay

Consequences

- Possible release of airborne radioactivity to canyon ventilation system

Safety Features

- Temperature controls
- Administrative controls

3.14.18 Leakage Through Cell or Canyon Wall (Ref. 24)

Causes

- Failure of embedded piping
- Seepage through cracks and expansion joints
- Penetration of conduit
- Holes drilled in wall

Consequences

- High, localized radiation or contamination in personnel areas

Safety Features

- Avoidance of expansion joints where possible
- Leak collection and detection at embedded pipe penetrations
- Stainless steel lining on lower 18 inches of walls and on floor
- Test sensor and sump alarm circuits. Separation of circuitry for alarm and pump-out functions.
- Leak collection and detection system beneath canyon floor

3.15 Crane Operations

3.15.1 Contamination in Crane Cab

Causes

- Deficiencies in the filter system of air conditioners
- Improper access to crane cab

Consequences

- Operator contamination

Safety Features

- Procedural control
- Double filters in series
- Provide controlled access to cab

3.15.2 Contamination of Crane External to Cab

Causes

- Violation of procedure by crane operator such as removal of cell covers during hot operation
- Equipment failure

Consequences

- Personnel exposure during decontamination

Safety Features

- Provide emergency exits
- Procedural control

3.15.3 Contamination of Work Areas by Crane Operations

Causes

- Operator error
- Dropped loads

Consequences

- Personnel exposure during decontamination

Safety Features

- Personnel training
- Procedural control
- Positive latching of materials moved by crane

3.15.4 Disengagement from Crane Hook

Causes

- Limit switch failure
- Incorrect setting of limit switch
- Broken bails
- Striking fixed object
- Moving at excessive speed
- Sudden loosening of jammed equipment

Consequences

- Equipment damage

Safety Features

- Personnel training
- Procedural control

3.15.5 Operator Mishandling of Crane

Causes

- Striking fixed object
- Snagging of fixed object with crane hook

Consequences

- Equipment damage

Safety Features

- Dead man controls
- Personnel training
- Procedural control

Safety Features

- Multiple sources of electrical generation (onplant as well as offplant)
- Area power taken from a loop with power coming from either direction on the loop
- Automatically started diesel generators

3.16.2 Failure to Supply Normal Electrical Power to Area Substation Switchgear

Causes

- Failure of area substation transformers
- Failure to supply area substation

Consequences

- Loss of all normal electrical power to facility

Safety Features

- Redundant transformers each capable of carrying the entire area electrical load
- Automatically started diesel generators

3.16.3 Failure to Supply Normal Electrical Power to Area Loop

Causes

- Failure of area substation switchgear
- Switching error
- Failure to supply area substation

Consequences

- Loss of normal electrical power to one leg of area loop

Safety Features

- Automatic tie-in of double-ended area loop
- Automatically started diesel generator

3.15.6 Crane Cable Damage

Causes

- Jamming
- Overload

Consequences

- Significant damage to critical equipment

Safety Features

- Cable overload devices
- Procedural control

3.15.7 Failure of Crane Components

Causes

- Electrical failure
- Mechanical failure

Consequences

- Increased personnel exposure for maintenance

Safety Features

- Redundant and fail-safe safety devices such as braking and optic system
- Periodic maintenance

3.16 Electrical Power Supply

3.16.1 Loss of Normal Electrical Power to Substation for Area (Ref. 2,5,41)

Causes

- Malfunction of both offplant and onplant generating systems
- Malfunction of transmission system to area substation

Consequences

- Loss of all normal electrical power to entire area

3.16.4 Failure to Supply Normal Electrical Power to Secondary Feeders

Causes

- Failure within the area loop
- Failure to supply the area loop

Consequences

- Loss of normal electrical power to one leg of area loop

Safety Features

- Automatically started diesel generators

3.16.5 Failure to Supply Electrical Power to Secondary Feeder Transformer

Causes

- Failure within the secondary feeder
- Failure to supply secondary loop

Consequences

- Loss of normal electrical power to equipment supplied by secondary feeder

Safety Features

- Automatically started diesel generators

3.16.6 Failure to Supply Power to a Motor Control Center (Ref. 1,5,41)

Causes

- Failure of secondary feeder transformer and/or of emergency diesel generator system
- Failure to supply secondary feeder and/or of emergency diesel generator system

Consequences

- Loss of all electrical power to equipment serviced by motor control center

Safety Features

- Redundant, vital equipment automatically supplied power from separate motor control centers
- Uninterruptible instrument power supplies

3.16.7 Failure to Supply Power to Operating Equipment (Ref. 41,42)

Causes

- Failure within motor control center
- Failure between motor control center and equipment
- Failure to supply motor control center

Consequences

- Failure of critical equipment or engineered safety features

Safety Features

- Redundant, vital equipment automatically supplied power from separate motor control centers
- Safety-related electrical equipment, including conduit, switchgear and motor control centers, shall be designated to meet seismic criteria and environmental conditions
- Redundant routings of power and control cables for safety-related circuits shall be run separately
- The electrical power systems important to safety shall be designed to include the capability for periodically testing the operability and functional performance of those system components and the operability of the system as a whole.
- Adequate lightning protection
- Concrete that encases buried conduit for power distribution is dyed red to indicate contents. Cable encasements for safety-related functions are maximum-resistance construction.

- Proximity of liquid-bearing lines above motor control centers should be avoided where possible
- Proximity of electrical equipment to thermally hot process equipment should be avoided where possible

3.16.8 Failure of Emergency Diesel Generator System (Ref. 2,5,40-42)

Causes

- Natural phenomena
- Failure to start
- Failure to continue running - mechanical
- Failure to continue running - fuel supply
- Accidentally turned off
- Switchgear failure
- Fire

Consequences

- Loss of backup electrical power to critical equipment

Safety Features

- Two separate maximum-resistance emergency power systems
- Primary oil supply tanks (day tanks) for diesels are maximum-resistance construction
- Either diesel is sized to carry full area emergency load with capability for manual switchover should one fail
- Autotransfer to emergency power: not responsive to momentary surges, sequential loading, automatic reset
- Emergency generator operating indication
- Battery charger
- Dual battery pack on diesel starter
- Diesel generator room is heated to maintain temperatures above freezing

- All emergency electrical equipment should be located to protect against steam, water, or process fluid leaks causing ambient temperatures or humidity to rise to a level that would cause electrical equipment malfunction
- Emergency electrical equipment should be protected from potential accident-generated flooding
- Fire consuming all the combustibles within one electrical enclosure cannot spread to redundant electrical equipment

3.17 Water Supply and Return

3.17.1 Failure of Well Pump (Ref. 43)

Causes

- Mechanical failure
- Electrical failure

Consequences

- Temporarily stops resupply of cooling water and depletes water reserve

Safety Features

- Provide sufficient inventory of water in cooling tower to achieve safe shutdown
- Install diesel power or steam-driven pump for backup

3.17.2 Cooling Tower System Failure

Causes

- Fire
- Catastrophic natural phenomena

Consequences

- Loss of cooling capability

Safety Features

- Redundant cooling tower system

3.17.3 Pump System Failure by Freezing

Causes

- Freezing weather

Consequences

- Depletes the water reserve

Safety Features

- Design for cold weather conditions

3.17.4 Failure of Normal Cooling Water

Causes

- Corrosion
- Ground settling
- Stress from adjacent roadway

Consequences

- Loss of cooling capacity

Safety Features

- Install independent header
- Install isolation valves
- Pressure sensors and alarms

3.17.5 Failure of Heat Exchanger

Causes

- Corrosion
- Pluggage

Consequences

- Cripples the cooling water supply system

Safety Features

- Multiple heat exchangers

3.17.6 Recirculating Cooling-Water Return-Pump Failure

Causes

- Electrical failure
- Mechanical failure

Consequences

- Temporary loss of cooling capacity

Safety Features

- Spare water return pump with automatic start

3.17.7 Closed-Loop Cooling Water Contamination

Causes

- Cooling coil failure
- Residual activity becoming dislodged
- Pressure system being valved off during shutdown of vessel with failed coil
- Heat exchanger leak

Consequences

- Increased radiation exposure to operating personnel

Safety Features

- Install manual diversion system
- Monitor cooling water for activity
- Backup coil pressure regulators on all heating coils with alarms

3.17.8 Radioactive Leakage Through Cooling Water to the Environment

Causes

- Failure to rapidly divert the contaminated cooling water
- Leak of contamination into cooling water with major breach of effluent piping

- Improper removal of contaminated sludge from the bottom of delaying basin
- Activity accumulation in the soil of the effluent ditch

Consequences

- Release of liquid-borne radioactivity to environment

Safety Features

- Sample analysis of water in holding basin
- Double holding basin for purge effluent

3.18 Steam Generation and Distribution

3.18.1 Leak in Steam or Cooling Coil Within Process Vessel

Causes

- Coil or tube failure from corrosion, vibration, fabrication error, improper material of construction

Consequences

- Activity release into segregated water

Safety Features

- Activity monitors and alarms in condensate discharge
- Manual diversion to retention basin
- Backup coil pressure regulators on all heating coils with alarms
- Double holding basin for condensate effluent

3.18.2 High Steam Pressure in Process Equipment (Ref. 5)

Causes

- Steam pressure regulator failure

Consequences

- Equipment failure
- Loss of temperature control, possibly leading to uncontrolled chemical reactions

Safety Features

- Automatic steam supply shutoff coupled with activation of cooling mode
- Pressure relief valve

3.18.3 Failure of Steam Supply (Ref. 5,42)

Causes

- Reduced steam supply due to boiler failure
- Reduced steam supply due to wet or low-grade coal
- Failure of 325 psi outside steam header
- Freezing of instrument at pressure reducing stations
- Severe condensate header leak

Consequences

- Loss of steam tracing in areas subject to freezing
- Potential reduction in removal efficiency of off-gas treatment units
- Loss of motivating steam to off-gas eductors

Safety Features

- Design pressure-reducing station for winter conditions
- Pressure instrumentation and alarms
- Temperature instrumentation and alarms

3.19 Cold Feed Facility

3.19.1 Leak (Ref. 5)

Causes

- Drain valve left open
- Piping change
- Corrosion of shell, drain plug, fitting, etc.
- Flange seal failure

Consequences

- Dispersion of noxious vapors

Safety Features

- Corrosion-resistant tanks
- Vessels and sumps equipped with liquid-level indicator and high-level alarms
- Transfer records
- All vessels equipped with facilities for drainage to sumps
- Dikes or curbing to contain vessel contents

3.19.2 Transfer Error (Ref. 5)

Causes

- Operator error (valving error, outlet left open)
- Line pluggage
- Defective valve
- Wrong tagging
- Unscheduled operation

Consequences

- Transfer to incorrect vessel within shielded canyons, to cell sumps, and to vessels outside shielded area
- Chemical addition error with possible chemical reaction or overflow

Safety Features

- Clearly labeled valves
- Procedures requiring verification

3.19.3 Overflow (Ref. 5)

Causes

- Failed to close valve, failed to follow procedures, inattention, unscheduled transfer, incorrect interpretation, recorder malfunction, misinterpreting chart, incorrect valve position

Consequences

- Possible release of noxious vapors

Safety Features

- Liquid-level indicator and high-level alarms on vessels and sumps
- Liquid-level interlock on pump controls
- All vessels equipped with facilities for drainage to sumps
- Dikes or curbing to contain vessel contents

3.19.4 Uncontrolled Reactions (Ref. 5)

Causes

- Chemical addition error
- Transfer error

Consequences

- Leads to foaming, boilover, explosion, eructation

Safety Features

- Sampling capability for specified vessels
- All tanks equipped with facilities for drainage to sumps
- Specified vessels equipped with liquid-level detector and agitator
- Separate acid and base sumps and overflow tanks
- Labels on all chemicals
- Separation of nitric acid and ammonia vessels and lines
- Dikes or curbing to contain vessel contents

3.19.5 Chemical Addition Error (Ref. 5)

Causes

- Operator error (inattentive, inexperienced, misreading, two jobs at a time)
- Misvalving

- Calculation error
- Mislabeled chemicals

Consequences

- Possible uncontrolled reaction

Safety Features

- Sampling capability for specified vessels
- All tanks equipped with facilities for drainage to sumps
- Vessels equipped with liquid-level detector and agitator
- Separate acid and base sumps and overflow tanks
- Labels on all chemicals
- Separation of nitric acid and ammonia vessels and lines
- Dikes or curbing to contain vessel contents

3.19.6 Transfer Line Pluggage (Ref. 5)

Causes

- Precipitation
- Sludge in head tank
- Filter pluggage
- Corrosion

Consequences

- Pumping against head can cause liquid to leak into wrong system
- Pluggages can result in loss of material

Safety Features

- Install filter and flowmeter
- Differential pressure instrumentation

3.20 Sampling Operations

3.20.1 Broken Sample Vial

Causes

- Sample vial and/or retainer ring installed improperly
- Hand sampling in lieu of using doorstop
- Dropped doorstop from hoist
- Dropped sample when lid came off

Consequences

- Personnel contamination

Safety Features

- Procedural control
- Preventive maintenance on hoist

3.20.2 Leak

Causes

- Gasket failure
- Air bleed line leak
- Corrosion of carbon steel supports allowing misorientation of components in sampler
- Secondary containment duct leak
- Valve failure
- Line cracked

Consequences

- Personnel contamination

Safety Features

- Minimize use of gasketed connections where possible
- Use of remotely operated shielded sample cell

3.20.3 Failure to Survey Person or Material Prior to Removal from Sample Aisle

Causes

- Violation of procedures

Consequences

- Potential for spread of contamination outside regulated area

Safety Features

- Provide monitoring equipment at exits from sampling areas
- Procedural control

3.20.4 Fire

Causes

- Welding operations
- Spontaneous combustion of waste

Consequences

- Equipment damage and/or airborne activity

Safety Features

- Fire detection and suppression equipment
- Procedural control

3.20.5 Improper Storage of Wastes or Equipment

Causes

- Failure to adequately seal waste cartons
- Failure to neutralize acid-soaked cellulose waste

Consequences

- Contamination of personnel and work area

Safety Features

- Procedural control

3.20.6 Hoist Failure

Causes

- Hoist came apart
- Chain link broke
- Electrical short
- Loss of contact through collector shoe

Consequences

- Spilled samples, contamination, or inability to process samples

Safety Features

- Preventive maintenance
- Reduced need for hoist for routine sampling by providing remotely operated shielded sample cells

3.20.7 Operator Error

Causes

- Inadequate training
- Failure to follow procedures

Consequences

- Radiation exposure to personnel, contamination, mixup of analytical samples

Safety Features

- Training of personnel

3.20.8 Pluggage of Sampler Needle

Causes

- Solids from ion exchange resin, particles of plastic dust covers, precipitation, over-concentration, and incidental use of sampler
- Needles cross-threaded
- Incorrect gasket installation

Consequences

- Inability to sample
- Exposure to personnel during blowdown
- Potential for spread of contamination during blowdown
- Pressurization of sampler

Safety Features

- Provide capability for removing pluggage by portable blowdown facilities

3.20.9 Radiation Exposure to Personnel

Causes

- Misinterpreted radiation tag
- Needle change
- Blowdown operations
- Failure to flush
- Leak
- Suckback
- Failure to wear respiratory equipment
- Failure of monitoring equipment
- Dropped samples
- Routine maintenance to samplers
- Vial cap fails to disengage from needle
- Failure of personnel to monitor
- Activity release near building air intake

Consequences

- Radiation exposure to personnel

Safety Features

- Use of remotely operated shielded sample cells
- Portable blowdown facilities
- Procedural control

3.20.10 Air Reversal

Causes

- Canyon cell flush with improper combination of doors open
- Reduced airflow for stack inspection
- Reduced airflow for electrical work
- Fan reversal as result of repair work
- Ducts covered with paper during painting operations

Consequences

- Potential for inhalation of activity by operating personnel

Safety Features

- Pressure differential alarm in affected process area

3.20.11 Failure to Obtain Sample or Analysis, or Delayed Analysis

Causes

- Sample radiation level too high to handle
- Tape left over sampler connection following maintenance
- Plugged dip tubes
- Failure to follow procedures
- Failure to communicate sampling instructions to sampling personnel
- Sampler cylinder stuck or other mechanical failures

Consequences

- Increased potential for action without adequate analysis

Safety Features

- Portable blowdown facilities
- Use of remotely operated shielded sample cells

3.20.12 Spill

Causes

- Operator dropped sample
- Failure to properly install retainer ring
- Valving error with subsequent overflow of funnel
- Vial cap fails to disengage from sampler needles

Consequences

- Radiation exposure to personnel, contamination

Safety Features

- Use of remotely operated shielded sample cells
- Procedural control

3.20.13 Contamination Through Expansion Joints

Causes

- Rainwater leakage and deteriorated expansion joint caulking

Consequences

- Contamination of sample aisle

Safety Features

- Minimize use of expansion joints in building construction

3.20.14 Injury to Personnel

Causes

- Loose compressed air line in sampler box
- Impaled by sampler needle
- Improper handling of hoist pendant

Consequences

- Possible lost work time

Safety Features

- Use of shielded sample cell

3.20.15 Sampler Pressurized

Causes

- Pluggage

Consequences

- Gross contamination of sampler box
- Increased personnel exposure

Safety Features

- Portable blowdown facilities
- Use of remotely operated shielded sample cells

3.21 Ventilation Systems

3.21.1 Loss of Stack Condensate to Environment

Causes

- Breach of stack drain piping

Consequences

- Contamination of environment

Safety Features

- Stainless steel lining covering floor and lower two feet of stack wall
- Stainless steel lined sump with alarm
- Dehumidifier on vessel vent air

3.21.2 Failure of Stack Sampling and Monitoring Systems

Causes

- Electrical failure
- Sampler line pluggage
- Mechanical failure of sampler exhauster fan

Consequences

- Failure to detect possible releases

Safety Features

- Emergency power system

3.21.3 Sand Filter Depression

Causes

- Water-soaked sand
- Eroded and/or corroded sandbed support

Safety Features

- Depression gauge and alarm
- Filtered air sampling, radiation monitor and alarm
- Stainless steel sandbed support over lateral ducts

3.21.4 Water Accumulation in the Sand Filter

Causes

- Leakage of water into sand filter
- Condensation in sand filter

Consequences

- Pressure differential buildup with reduced air flow
- Possible leakage of radioactive airborne materials to environment

Safety Features

- Air dehumidifier on vessel vent system
- Stainless steel lined sump pits under sand filter
- Roof and sides sealed and drained to prevent water from leaking into sand

3.21.5 Canyon Exhaust Fan Failure

Causes

- Mechanical failure (bearing, shaft, belt)
- Motor failure
- Mounting foundation and/or bolt destroyed
- Split of a welded seam
- Fan control wire burned

Consequences

- Possible loss of ventilation

Safety Features

- Paralleled backup canyon exhaust fan system with automatic start
- Emergency power with automatic start
- Alarm to indicate lack of airflow

3.21.6 Circuit Breaker Switch Failed

Causes

- Shorted by rain
- Lightning

Consequences

- Loss of ventilation

Safety Features

- Circuit breaker switch in weather-proof box
- Lightning protection

3.21.7 Power Failure to Motor of Air Exhaust Fan

Causes

- Power failure
- Circuitry failure

Consequences

- Failure of ventilation system
- Air reversal to personnel areas

Safety Features

- Paralleled backup system with automatic start
- Install emergency power supply system with automatic start

3.21.8 Vacuum Lost in Process Vessel Vent System

Causes

- Line pluggage
- Lack of required maintenance
- Plugged vessel vent filter

Consequences

- Increased activity in canyon exhaust

Safety Features

- Pressure instrumentation and alarm
- Parallel system with bypass valving capability

3.21.9 Damper Failure

Causes

- Loss of instrument air
- Solenoid burned

Consequences

- Loss of ventilation and possible air reversals and personnel uptakes

Safety Features

- Automatic and manual control capability on dampers
- Alarm to indicate lack of airflow

3.21.10 Mechanical Failure of Fan in Process Vessel Vent System

Causes

- Bearing failure

Consequences

- Loss of process vessel vent system with subsequent release of activity to cell air

Safety Features

- Backup system for emergency use with automatic start and alarm

3.21.11 Electric Power Failure in the Process Vessel Vent System

Causes

- Lightning

Consequences

- Loss of process vessel vent vacuum

Safety Features

- Parallel backup system with automatic start
- Emergency power system with automatic start

3.21.12 High Ruthenium Adsorber Bed Temperature (Ref. 5)

Causes

- Excessive ruthenium loading
- Inadequate bed cooling

Consequences

- Increased ruthenium release to building ventilation filters

Safety Features

- Temperature alarm instrumentation

3.21.13 HEPA Filter Leakage in Melter-Calciner Off-Gas System (Ref. 2)

Causes

- Punctured
- Improper installation
- Vibrated loose

Consequences

- Release of airborne radioactivity to environment

Safety Features

- Filters in parallel and series with activity alarm
- DOP testing of filters

3.21.14 High Pressure Drop Across HEPA Filters (Ref. 5)

Causes

- Pluggage
- Excessive moisture in vent air
- Excessive generation of fine particulates

Consequences

- Release of activity to the atmosphere during the replacement

Safety Features

- Pressure differential monitoring on the HEPA filters

3.21.15 Filter Pluggage in the Process Vessel Vent System

Causes

- Ammonium nitrate buildup
- Other solids

Consequences

- Loss of process vessel vent vacuum

Safety Features

- Delta-p instrumentation across the filter

3.21.16 Air Reversal (Ref. 1)

Causes

- Pressure imbalance caused by 1) fan failure (supply or exhaust), 2) damper failure, 3) doors left open

Consequences

- Area or personnel contamination

Safety Features

- Differential pressure gauge and alarm in appropriate areas
- Automatic and manual damper control

3.22 Gang Valve Operations

3.22.1 Fire

Causes

- Welding
- Electrical short

Consequences

- Damage to insulation, combustibles, and waste with possible spread of contamination

Safety Features

- Procedural control
- Fire detection and suppression equipment
- Minimize use of combustible materials

3.22.2 Radiation Exposure to Personnel

Causes

- Performance of unauthorized work
- Inadequate preplanning for job
- Pluggage, waste back-up through floor drain
- Suckback
- Valving error
- Inadequate monitoring
- Leaks
- Piping error
- Spill into uncovered vacuum breaker vent line

Consequences

- Radiation exposure to personnel

Safety Features

- Elevation of gang valves above process vessels to reduce severity of suckbacks
- Automatic air blow on gang valves

3.22.3 Mechanical or Electrical Failure of a Gang Valve

Causes

- Electrical short
- Leak
- Bellows failure
- Limit switch failure
- Stuck in one position
- Timer failure
- Motor mount broken
- Valve installed backwards
- High heat and humidity causes electrical junction failures

Consequences

- Inability to transfer
- Inability to stop transfer

Safety Features

- Mechanical means to overcome electrical failure and manual valves as backup for mechanical failure

3.22.4 Injury to Personnel

Causes

- Burn from hot equipment

Consequences

- Possible lost work time

Safety Features

- Procedural control
- Insulate all hot lines

3.22.5 Suckback

Causes

- Condensation of steam causes partial vacuum in system that pulls process fluids into gang valve
- Failure of process air system

Consequences

- High radiation in personnel areas

Safety Features

- Automatic air blow on gang valves
- Isolation valve actuated by radiation monitor
- Elevation of gang valves above process vessels to reduce severity of suckbacks

3.22.6 Leak

Causes

- Gasket failure
- Valve failure
- Line cracked
- Embedded pipe corrosion
- Condensate header failure

Consequences

- Contamination of personnel

Safety Features

- Routine inspection
- Radiation monitoring equipment
- Constant air monitors

3.22.7 Transfer Error

Causes

- Incorrect gang valve unlocked - verification not made
- Failure to stop and lock out gang valve on transfer from tank before energizing gang valve on transfer into tank
- Failure to lock out gang valve following transfer - gang valve is later actuated by accident
- Misreading valve identification, accidentally bumping start button, and mislabeled panel board

Consequences

- Transfer to incorrect vessel within shielded canyon, to cell sumps, and to vessels outside shielded area

Safety Features

- Valve numbering system should correspond to numbers used in procedure

3.22.8 Failure to Survey Person or Material Prior to Removal from Gang Valve Corridor

Causes

- Violation of procedure

Consequences

- Potential for spread of contamination outside regulated area

Safety Features

- Provide monitoring equipment at exits from gang valve areas
- Training of personnel

3.23 Shops and Decontamination Facilities

3.23.1 Transfer Error of Contaminated Solutions

Causes

- Personnel error

Consequences

- Transfer to incorrect vessel within shielded canyon, to cell sumps, and to vessels outside shielded area

Safety Features

- Dedicated piping and valving
- Radiation monitor and alarms of any lines transferring decontaminated solution outside building. Ability to return material from outside building to canyon.

3.23.2 Overflow of Contaminated Decontamination Solution

Causes

- Personnel error

Consequences

- Release of liquid-borne radioactivity to cell sump

Safety Features

- Install liquid-level indicators and alarms

3.23.3 Leak of Contaminated Materials

Causes

- Corrosion

Consequences

- Release of radioactive material to cell sump

Safety Features

- Stainless steel liner in specified areas
- Sump and alarm

3.23.4 Personnel Exposure to Radiation

Causes

- Failure to follow procedures

Consequences

- Personnel contamination
- Excessive exposure

Safety Features

- Personnel monitoring system

3.23.5 Airborne Activity in Shops and Decontamination Cell

Causes

- Overheating of decontamination solution

Consequences

- Personnel contamination and possible uptake

Safety Features

- Adequate ventilation system
- Radioactivity monitoring

3.24 Compressed Air and Compressed Gas Systems

3.24.1 Plant Air System Failure

Causes

- Compressor failure
- Electrical supply failure
- Compromise of air carrier from rupture or valving error

Consequences

- Increased likelihood of activity entering the the cooling water system because of failure of air controller for steam/water coils

Safety Features

- Redundant compressor system with automatic start
- Automatic isolation of system if loss of pressure occurs to prevent backflow of contamination
- Instrumentation and alarms for system pressure and compressor operability

3.24.2 Instrument Air System Failure

Causes

- Compressor failure
- Electrical supply failure
- Compromise of air carrier from rupture or valving error

Consequences

- Negates effectiveness of many instruments but does not in itself cause a release of activity, nor prevent emergency shutdown of operations

Safety Features

- Redundant compressor system with automatic start
- Automatic isolation of system if loss of pressure occurs
- Instrumentation and alarms for system pressure and compressor operability

3.24.3 Process Air System Failure

Causes

- Compressor failure
- Electrical supply failure
- Compromise of air carrier from rupture or valving error

Consequences

- Increased potential for suckback through gang valves

Safety Features

- Redundant compressor systems with automatic start
- Automatic isolation of system if loss of pressure occurs
- Instrumentation and alarms for system pressure and compressor operability

3.24.4 Breathing Air System Failure

Causes

- Compressor failure, electrical supply failure coupled with failure of backup manifold system
- Incorrect gas charged to breathing air cylinders
- CGA (Compressed Gas Association) connections for nitrous oxide, helium, carbon dioxide, argon with 20% oxygen, and nitrogen with 18.65% oxygen will mate with breathing air connections, even though some leakage would be likely.
- Failure of breathing air hose due to leaks or kinks
- Contamination of cooling water to breathing air compressor
- Oil in breathing air due to use of improper compressor
- Vortex tube frosted internally

Consequences

- Personnel injury
- Delay in maintenance

Safety Features

- Redundant compressor systems with automatic start or adequate storage capacity for removing personnel in event of failure
- Instrumentation and alarms for system pressure and compressor operability
- Filtration system for removal of oil and other impurities
- Redesign of breathing air connections to protect against accidental connection of other gases

- Analysis of contents of breathing air cylinders
- Inspection and testing program for breathing air hoses
- Use of kink-resistant breathing air hoses

3.24.5 Fire

Causes

- Valving error with flammable gases such as acetylene
- Leaks in flammable gas system

Consequences

- Release of airborne radioactivity to canyon ventilation system

Safety Features

- Fire detection and suppression systems

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Authors of specific suggestions, in order of incidents, are as follows.

Incident	Title	Source
1.4.2	Filter Fire in Vessel Vent Lines	R. F. Bradley, D. C. Witt, C. T. Randall
1.5.2	Red Oil Explosion in an Evaporator	D. C. Witt
1.5.3	Eructation in Evaporator, Dissolver, or Acid Recovery Unit	D. C. Witt
1.5.4	Explosion in Vessel Vent System	L. F. Landon & V. Van Brunt
1.5.5	Calciner Eructation	C. B. Goodlett
1.6.1	Leak in Pool Water Treatment System	W. H. Baker & F. D. King
1.8.1	Failure of Exhaust or Supply Motor	W. H. Baker & F. D. King
1.9.1	Failure of Exhaust Blower	R. F. Bradley, D. C. Witt, C. T. Randall
1.9.3	Capacity of Off-Gass System Overload	W. J. Jenkins, S. D. Harris, J. T. Ratliff
1.9.4	Ruthenium Escapes to Off-Gas System	D. C. Witt
1.10.7	Loss of Cooling	W. H. Baker & F. D. King
1.10.9	Suckback into Gang Valve	C. T. Randall & L. F. Landon
2.1.5	Cask Inadvertently Vented	W. H. Baker & F. D. King
2.1.10	Water Pumped into Sodium Storage Tank	J. N. Herndon
2.1.25	Cooling Towers Become Inoperative	W. H. Baker & F. D. King
2.1.26	Loss of Normal Cooling Water	W. H. Baker & F. D. King
2.2.1	Pyrophoric Fire	J. P. Faraci
2.2.2	Fuel Jammed or Stranded in Shear	J. P. Faraci
2.3.1	Escape of Powder from Reaction Vessel	J. T. Ratliff
2.4.1	Uncomplexed Fluoride in Dissolvent	W. J. Jenkins
2.4.2	Pu-Rich Residue Settling in Dissolver, Lines, and Other Process Vessels	W. J. Jenkins

Incident	Title	Source
2.4.3	Overloading Capacity of Off-Gas System	W. J. Jenkins
2.4.4	Precipitation of Pu Polymer	W. J. Jenkins
2.4.5	Overpressurization of Stored Fuel Cans	W. J. Jenkins
2.4.6	Contact of Sheared Fuel at Temperatures About 300°C above Boiling Point of Dissolver Solution	W. J. Jenkins W. J. Jenkins
2.4.7	Zirconium Fire	W. J. Jenkins
2.4.8	Zirconium Explosion	W. J. Jenkins
2.5.1	Pu Concentration in a Solvent Extraction Contactor Increases Beyond Normal Values	M. C. Thompson
2.7.1	Ruthenium Escapes to Stack	D. C. Witt
2.7.2	Leaks	D. C. Witt
2.8.1	Explosion in ARU	D. C. Witt
2.8.2	Leaks in ARU System	D. C. Witt
2.8.3	Eructation in ARU	D. C. Witt
2.9.1	Uncontrolled Reaction Between Nitric Acid and the Anion Exchange Resin in the PRC (Primary Recovery Column)	D. C. Witt
2.12.1	Pluggage of Instrument Lines and Sensors	C. B. Goodlett
2.20.1	Ammonium Nitrate Explosion in Calciner	J. H. Radke
2.23.1	High Activity Level in the Storage Pod Water	W. H. Baker
2.23.2	Contaminated Canisters	W. H. Baker
2.23.3	Loss of Cooling Water and Shielding	W. H. Baker
2.23.4	Canister Stress Corrosion	W. H. Baker
2.23.5	Canisters Raised above Adequate Shielded Level	W. H. Baker
2.23.6	Water Loss from Storage Pool	W. H. Baker
2.23.7	Canisters Leak Radioactive Waste	W. H. Baker
2.23.8	Water Leaks into the Canister	W. H. Baker
2.23.9	Fires in the Waste Handling Facility	W. H. Baker
2.23.10	Canisters Dropped During Handling	W. H. Baker
2.24.1	Fire in Fuel Hardware Fixation Area	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp
2.24.2	Drum Overflow in Fuel Hardware Fixation Area	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp

Incident	Title	Source
2.24.3	Airborne Cement Dust in Grout Mixer Area	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp
2.24.4	Radioactive Contamination in Cement Preparation Area (Cold Area)	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp
2.24.9	Fire in Beta-Gamma Waste Facility	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp
2.24.10	Airborne Activity in the Beta-Gamma Waste Facility	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp
2.24.11	Violation of Stack	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp
2.24.14	Criticality Potential in Alpha Waste	T. J. Pazik, H. E. Hootman, P. H. Permar, D. J. Trapp
3.5.3	Hydraulic Surge	E. C. Bertsche
3.5.4	Failure of Backflush System to Operate	E. C. Bertsche

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