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REGULATORY GUIDE

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REGULATORY GUIDE 5.25

DESIGN CONSIDERATIONS FOR MINIMIZING RESIDUAL HOLDUP OF SPECIAL NUCLEAR MATERIAL IN EQUIPMENT FOR WET PROCESS OPERATIONS

A. INTRODUCTION

Section 70.22 "Contents of applications," of 10 CFR Part 70, "Special Nuclear Material," requires, among other things, that each application for a license to possess at any one time more than one effective kilogram of special nuclear material (SNM) contain a full description of the applicant's program for control of and accounting for SNM which will be in his possession under license, including procedures for controlling SNM during its processing or use in the facility. Section 70.51, "Material balance, inventory, and records requirements," requires, among other things, that certain licensees conduct their nuclear material physical inventories in compliance with specific requirements set forth in 10 CFR Part 70.

The control of and material balance accounting for SNM can be made more effective by reducing residual holdup in process equipment following draindown or following draindown and cleanout. This would lessen the severity of problems associated with determination of the residual holdup component of a physical inventory and would reduce the component of uncertainty contributed by residual holdup to a physical inventory.

This regulatory guide describes design features and characteristics acceptable to the Regulatory staff for minimizing the residual holdup of SNM after draindown or cleanout of equipment used in wet process operations. These features and characteristics are expected to facilitate physical inventory measurements and ameliorate material balance uncertainties without interfering with process operations. In particular, this guide is addressed to operations including (1) liquid blending and gas-liquid contacting, (2) liquid transfer and storage, (3) precipitation, (4) slurry transfer, and (5) liquid-solid separations.[1]

B. DISCUSSION

1. Background

Past experience and current observation of the unit operations used in operating systems at plants for chemical conversion, fuel fabrication, scrap recovery, and fuel reprocessing indicate that publication of general guidance for equipment design could assist in achieving the degree of material control that is essential for satisfactory protection of SNM. In processing, SNM may accumulate as a sizable deposit which increases during processing, or SNM may accumulate only during draindown. For a given process, mode of operation, and type of material, the amount of holdup may fluctuate near some characteristic value. In other cases, the quantity accumulated may continue to increase as operation continues and become apparent as residual holdup only upon draindown or cleanout.

It is often difficult to determine the quantity of SNM holdup with sufficient precision and accuracy to meet the MUF and LEMUF requirements of Section 70.51. This determination usually includes locating, sampling, identifying, and analyzing the SNM. Appropriate design not only could assist in reducing residual holdup and consequent need for determination, but also could assist in increasing the effectiveness of draindown and cleanout, if necessary.

[1] Regulatory Guide 5.8, "Design Considerations for Minimizing Residual Holdup of SNM in Drying and Fluidized Bed Operations," is a parallel guide.

With unknown or imprecisely known quantities of residual holdup in equipment, the effectiveness of a material balance as a control mechanism is seriously impaired. Minimizing the quantity of material retained in process equipment generally enhances the effectiveness of a material protection program in the following ways.

a. Quality of Physical Inventories

The extent to which inaccuracy and uncertainty in measured residual holdup detracts from a physical inventory depends on the amount of holdup and the uncertainty in that amount. Therefore, the influence of this uncertainty on the LEMUF (limit of error on material unaccounted for) can be reduced directly by reducing residual holdup. By reducing the quantity of material that cannot be measured well, the quality of the physical inventory[2] is improved. In addition, the contribution of unmeasured holdup to the MUF (material unaccounted for) can be reduced.

In general, one of the influential factors which must be controlled to achieve a satisfactory inventory is the presence of residual holdup and its influence on inventory uncertainty. For a process amenable to dynamic inventory techniques, in particular, credibility in the technique itself would be increased by reducing or removing the uncertainty of residual holdup.

b. Susceptibility of SNM to Diversion

Reduction of the quantity of residual holdup following draindown or draindown and cleanout of process equipment decreases the quantity of SNM which is susceptible to diversion during sampling and identification and subsequent separation, recycle, or recovery as appropriate.

Decreasing the residual holdup limits the effort necessary to establish the presence of residual material and to remove it for a physical inventory. Consequently, the amount of time SNM is accessible and the number of people who need access to it are reduced, and the opportunity for unauthorized individuals to gain access to SNM during this stage of a physical inventory is reduced. Where the effects of residual holdup are negligible, an in-process or dynamic inventory method might be utilized, thereby reducing direct contact (i.e., accessibility) of inventory personnel with SNM.

Automated processes have the effect of directly limiting personnel access to SNM during normal operation. A dynamic or in-process inventory may be conducted for an automated process line; this would continuously limit access to SNM. Consequently, it is beneficial to consider the effects of residual holdup early in the stages of equipment design, particularly if shutdown and cleanout could be avoided for an entire automated process (e.g., chemical conversion facility) or a remotely operated process (e.g., fuel reprocessing plant).

2. Unit Operations

This guide is addressed to reducing residual SNM holdup in five unit operations common to wet chemical processes. These are described in the following paragraphs. For purposes of this discussion, the term "significant amounts" refers to those quantities which may cause difficulty in satisfying the inventory quality requirements of Section 70.51.

a. Liquid Blending and Gas-Liquid Contacting

Gas-liquid contacting refers to the reaction of a gas with a liquid to yield a liquid product. An example of a gas-liquid reaction is the hydrolysis of uranium hexafluoride to form an aqueous solution of uranyl fluoride, which then may pass to a precipitation operation.

Liquid blending is used, for example, to produce a uniform mixture of uranium and plutonium nitrate solutions which subsequently may pass to a coprecipitation operation or be transferred to a fluid bed drier. To prevent the formation of polymeric species of plutonium during mixing, control of the temperature and acidity of plutonium nitrate or of mixed nitrates is necessary.

A distinguishing characteristic of gas-liquid contacting and liquid blending is that the bulk material is a liquid; solids normally are not expected to be present. In general, draindown of equipment used for the operations can be enhanced significantly if accompanied by rinsing. To remove residual deposits of any plutonium polymer formed, additional cleaning may be necessary.

b. Liquid Transfer and Storage

Liquids containing SNM are transferred and stored throughout a number of chemical conversion processes and fuel reprocessing steps. For example, uranium and plutonium nitrate solutions or uranyl fluoride solutions are transferred between vessels. Also, waste solutions may be transferred from liquid-solid separating operations to temporary storage tanks or evaporating ponds. Tanks are utilized for feed adjustments, dissolution, accountability, settling, surge, and product collection.

In general, a low level of residual holdup can be achieved if equipment used for transfer and storage of liquids is flushed out or rinsed after draining. However,

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[2] Regulatory Guide 5.13, "Conduct of Nuclear Material Physical Inventories," addresses the subject of conducting physical inventories for nuclear material.

precipitation of solids or buildup of salt on vessel walls may resist meager attempts at rinsing.

c. Precipitation

In precipitation reactions, SNM in aqueous solution is converted to solid form by the addition of a precipitating agent. The resulting solid initially is in suspension but may undergo settling. Holding or aging tanks may be used for purposes such as crystal growth, chemical adjustment, or buffer storage.

This type of unit operation is used for the conversion of uranyl fluoride to ammonium diuranate (ADU); uranyl nitrate to ADU; plutonium nitrate to plutonium peroxide, oxalate, or hydroxide; and mixed uranium-plutonium nitrates to mixed ADU-plutonium hydroxide. An additional application is the conversion of uranium-containing and/or plutonium-containing solutions to sols.

In general, draindown of equipment used for precipitation operations may leave a significant quantity of residual holdup.

d. Slurry Transfer

Slurry transfer is the movement of a liquid in which solid or semisolid materials are suspended. An example is the transfer of slurries from precipitation operations (mentioned in section B.2.c. above) to separating or drying operations. Gels or sols containing uranium and/or plutonium also may be transferred as slurries.

Draindown of equipment used for this operation without cleanout may leave a significant quantity of material as holdup.

e. Liquid-Solid Separations

Unit operations currently utilized to achieve liquid-solid separation, including dewatering or solvent removal, are centrifugation, filtration, and settling. Liquid-solid separations separate bulk liquids from suspensions or slurries of solids and consolidate the solid material as a damp cake for subsequent operations. By means of liquid-solid separations, SNM-containing material from enrichment or fuel reprocessing plants may be converted to a form suitable for fuel fabrication. Draindown of the equipment may leave a significant quantity of residual holdup.

Operations that result in a dry solid product (e.g., drying and fluidized bed operations) are not included in this unit operation and are the subject of a separate regulatory guide.[1]

3. Holdup in Liquid Blending and Gas-Liquid Contacting

Many types of contactors (e.g., mixer-settlers, mixer columns, scrubbers, etc.) are used for liquid blending and gas-liquid reactions to produce liquid products. Although pulse columns may be preferred for liquid-liquid contacting, centrifugal contactors have the advantage of low holdup volume. Therefore, a small decrease in inventory error can be realized by using centrifugal contactors rather than pulsed columns. Disadvantages of centrifugal contactors are thay they are expensive and must be constructed to small tolerances. Furthermore, the kinetics of some reactions are not favored by the use of centrifugal contactors.

Liquid holdup in liquid blending and gas-liquid contacting equipment can occur at low spots in lines, in pump cavities, and in vessels without bottom outlets. Internally mounted equipment such as mixers, baffles, and spray rings provide additional surfaces where material can collect. However, as is true for most processes in which solids are absent, liquid products generally can be readily removed by gravity, i.e., by simply draining and flushing.

More complex problems are encountered when plutonium in solution forms polymeric species of a colloidal or gelatinous character that makes their removal from equipment difficult. Acidification can, at least partially, resolubilize the polymer, but kinetics limit the rate at which this occurs. To improve the ability of a facility to meet accountability requirements, it may be necessary to provide cleanout capability in those units of equipment where polymers could conceivably form.

4. Holdup in Liquid Transfer and Storage

Liquids are stored in various kinds of vessels and are transferred to process equipment through piping systems by means of gravity, pumps, steam or air jets, air lifts, or vacuum. When liquid is transferred by any of the above means, holdup problems can result from the existence of stagnant zones, low points in lines, or incomplete draining of equipment. As for the previous unit operation, internally mounted equipment such as mixers, baffles, and spray rings provide surfaces where material can collect. Therefore, equipment design effectively could be directed toward improved draining, supplemented by provisions for rinsing and flushing.

Gravity flow of material in a process is beneficial since it provides a degree of self-action (automation) for draining and flushing operations. Feed solution pumped to the highest point in a process would then cascade downward through the process network. Transfer lines for the entire process would be sloped for better overall drainage. However, even with an entire system designed inherently for free drainage, excessively flushing out the wet end of a process to reduce the quantity of SNM in the equipment for inventory purposes can produce a large quantity of dilute solution that is unsuitable for processing. Consequently, vacuum transfer and removal of solutions may be preferable.

More onerous holdup problems include the buildup of sludges in the bottoms of tanks used for accountability, transfer, or storage and the residual jet heels that remain after such tanks are emptied. Dissolution tanks have been constructed of stainless steel and Teflon-coated stainless steel (for other than irradiated service); the latter is preferred for purposes of reducing surface accumulation. Storage tanks and other vessels should be accessible for the installation of sensing devices such as dip tubes or inductive and sonic level detectors. This recommendation should be considered in view of other factors such as shielding and protecting vessels containing SNM from severe weather by embedding the vessels in concrete.

5. Holdup in Precipitation

Slurries and suspensions formed by precipitation can be removed readily from vessels by simple draining if settling does not occur. Loosely adhering solids on vessel walls can be dislodged by flushing. In sustained operations, however, solids may deposit on and adhere to surfaces in a manner that makes removal difficult. Agitation, which is provided principally to enhance particle agglomeration, reduces but does not eliminate this deposition of solids. In the preparation of sols using precipitation as a process step, agitation is necessary to resuspend the precipitate. The amount of deposited solids usually is sufficiently large to necessitate total cleanout for a physical inventory.

Several troublesome problems are related to residual holdup during precipitation and digestion. Where internally coated vessels are used for processing (e.g., Teflon-coated glass for fuel particle preparation), a positive seal should be assured between the lining and the vessel walls to prevent accumulation of particles in annular spaces between the two surfaces. Another problem can be the oxidation of intermediate compounds to undesirable compounds that may be gummy and insoluble. This could cause plugging of equipment and process piping if not controlled. For example, PuF_3 may oxidize to $PuF_4 \cdot 2.5H_2O$. In addition, some process intermediates (e.g., PuF_3) or interferents (e.g., polymers of plutonium) have a tendency to deposit on the surfaces of vessels used for precipitation and digestion. Plugging can be caused when flakes or globules of the deposits break loose from the surface and flow to a constriction such as an outlet or other piping. A more serious consequence of such deposits of SNM may be the hazard from accumulation of large yet unknown quantities.

Use of antioxidants and efficient agitation can assist in preventing these problems of holdup. The composition of the materials of construction as well as the condition of the interior surfaces of vessels (e.g., roughness or texture) may equally influence residual holdup prevention. The differences between these two factors may indeed be subtle.

Where deposits form on equipment surfaces, ultrasonic treatment can be effective for removing deposits. Such a cleaning technique may be needed if other methods of altering process conditions (e.g., use of surfactants) or modifying process equipment (e.g., electrostatically charging polyethylene vessels or maintaining polished internal surfaces) are ineffective.

Unfortunately, anomalous situations may arise if it is not possible to identify a deposit sufficiently to understand its properties. For example, flaking of deposits and consequent plugging of piping downstream can be decreased by flushing precipitator vessels with acid between batch runs. However, reduced plugging can be a result not only of the acid dissolving the deposits but also of the acid causing the deposits to be more adherent. More adherent deposits are less likely to flake off and plug the equipment, but large quantities may accumulate.

6. Holdup in Slurry Transfer

Slurries are transferred from one process vessel to another by methods that are essentially the same as those used to transfer liquids. However, holdup problems are more complex for slurry transfer because of a tendency of the suspended solids to settle out of the carrier liquid. Although different materials exhibit different settling characteristics, a critical velocity exists below which particles begin to settle out. Such settling is most likely to occur at shutdown or when flow rates are reduced because of abnormal operations. In such situations, pumps and valves may act as sites in which solids can accumulate or be trapped.

Cavities and recesses in pumps used to transfer slurries or suspended solids can collect significant quantities of solid material that are difficult to flush out. Transferring material by jets or gas lifts may minimize this difficulty.

When screw conveyors are used to transfer moist pastes, a coarse intermediate cleanout may be necessary for operational reasons, i.e., to prevent subsequent plugging of the process line. Additionally, a more complete cleanout may be needed at the end of each run. Because frequent cleanouts are necessary for operational reasons alone, a paste transfer method necessitating less interruption is desirable.

7. Holdup in Liquid-Solid Separations

Unit operations used for the separation of liquids and solids are centrifugation, filtration, and settling of slurries. A wide variety of devices is used for this operation. The type selected is dependent on the nature of the material being processed, the throughput rate, and the liquid content of the feed and product. Holdup problems are discussed below in connection with the type of equipment and the characteristics of the process material.

a. Centrifuges

In facilities with high throughputs, two centrifuges in series are typically used for separation. A primary centrifuge for separation and recovery of bulk solids is upstream from a clarifying centrifuge for removal and recovery of residual trace solids. The principal purpose of the primary unit is to produce a concentrated solid product having a relatively low water or solvent content. The second centrifuge serves principally for clarifying the centrate (i.e., the centrifuge effluent) from the first centrifuge. In processes in which the centrate from the first unit is not recycled through the fuel preparation process, the clarification step serves to recover residual SNM before the centrate is transferred to waste treatment.

Most of the material held up in a centrifuge after draindown exists as unremoved solids. In a batch basket-type centrifuge, holdup is normally small after unloading by normal procedures. However, in a solid-bowl continuous centrifuge equipped with a helical conveyor to remove solids, any solids deposited on the surfaces of the flights of the conveyor, on bowl surfaces in the clearance space between the flights of the conveyor and the bowl, and on surfaces of the solids-discharge cavity are difficult to remove. Simple flushing is not likely to be effective in dislodging solids, either from surfaces contacted by the flush or surfaces inaccessible to the flush. Comparable difficulties occur with other types of centrifuges, especially continuous centrifuges having complex unloading mechanisms.

b. Filters

In facilities having low throughputs or in facilities handling highly enriched uranium or plutonium, dewatering may be effected by continuous (e.g., rotary) filters or batch filters. For reasons of criticality control, this equipment is typically small in size. Following draindown, less material may be held up in filters than in centrifuges.

Although batch filters and drum filters have readily exposed surfaces that can be cleaned out by simple flushing or mechanical removal, it is difficult to clean out other types of filters, e.g., plate-and-frame presses. Leakage and bypassing of material can occur around the edges of a filter drum used in a continuous process line; pan filters have better cake removal than do drum filters. In filters such as those using a metal grid to support a paper filter medium, fines can lodge in the interstices of the equipment.

Parts of the separation system exposed to centrates and filtrates usually can be drained readily, but simple flushing probably does not remove solids adequately. Cleanout of plate-and-frame filter presses in particular can be difficult since centrates and filtrates each contain suspended solids, and sustained normal operation results in holdup of solids.

C. REGULATORY POSITION

For purposes of facilitating the measurement and/or recovery of residual special nuclear material held up in process equipment and to improve the accuracy and reliability of a physical inventory, the amount of SNM held up in equipment should be minimized. The design of equipment used to carry out physical or chemical changes on special nuclear material by wet operations, including liquid blending, gas-liquid contacting, liquid transfer and storage, precipitation, slurry transfer, and liquid-solid separation, should incorporate features that minimize residual holdup. Some appropriate equipment design features and characteristics whose use is generally acceptable to the Regulatory staff for this purpose are described in the following paragraphs. These should be implemented to the extent practicable. Usage also should be consistent with quality assurance, health, and nuclear safety codes that may be applicable.

1. General Design

a. Vessels, piping, valves, and accessory equipment should be designed to minimize undrained volume and should be free draining where practicable.

b. Inside surfaces of equipment should be free of crevices, cracks, protrusions, and other irregularities that could entrap material.

c. Surfaces that contact SNM should be selected and coated, polished, or machined to prevent or resist the adherence of liquids or solids.

d. Overlapping metal surfaces in contact with process material should be avoided except where sealed by welding; internal welds should be ground flush with inner surfaces. Exceptions may be gasketed openings such as inspection and cleanout doors or ports.

e. The internal angles, corners, and recesses should be rounded with a radius larger than a minimum radius, for example, one fourth inch.

f. Seams that may promote corrosion should not be used.

g. Materials of construction that contact SNM in any form should be selected to minimize corrosion, dissolution, or erosion of surfaces during operation or during contact with rinse solutions used for cleaning.

h. Structural integrity should be adequate to resist formation of leaks, cracks, and crevices due to stresses such as thermal and vibratory stresses. Accordingly, valves and pumps should be installed so as to minimize stresses on attached piping and vessels.

i. The influence of operating variables such as material flow rate, pH, concentration, and temperature should be evaluated to reduce undesirable formation of holdup (e.g., caking or sticking) that might be induced by operating in an undesirable range of operating conditions.

j. Flow control valves should have a minimum of internal holdup or obstruction to flow and should be installed in a location and position that enhances draining of the entire piping network.

k. Pipe lines for slurries or suspensions should be sized according to process flow requirements so that flow velocity is above the critical velocity at which settling can occur.

l. Material that contains solid forms of SNM, e.g., slurries and filtrates, should be transferred continuously to avoid settling.

m. Process units should be closely coupled and sized, with minimal intervening holdup tanks.

n. Equipment design should eliminate as many areas of stagnation and residual accumulation of solutions and slurries as possible (e.g., in order to facilitate the capability for conducting dynamic inventories).

2. Internal Design

a. Equipment should have a minimum of internal components upon which process material can collect. For example, bowls, product chambers, and centrate collection chambers of centrifuges should be designed to be free of nonessential protrusions and ledges. Additional surfaces in the form of helical conveyors, liquid accelerating bars, and devices for removing slurries should be kept to a minimum.

b. The use of internal mechanical agitators in blenders should be avoided. If agitators are used, they should be designed to permit surfaces to drain freely and to present minimum surface for the collection of solid particles. Seals such as self-sealing packing glands and cone pressure seals for maintaining a tight seal around stirring shafts should necessitate minimal maintenance.

c. Sensing devices such as thermocouples or level detectors should be installed in a manner that minimizes the amount of solid material that can be retained on the surfaces of such devices.

d. Extended surfaces such as packing (e.g., Raschig rings, Berl saddles, etc.) should be avoided. Permanently mounted process equipment internals that cannot be removed for cleaning should be designed to allow rinsings and normal contents of vessels such as liquid blenders to drain freely from the bottom of the equipment. If extended surfaces are necessary, the licensee should be able to demonstrate that an acceptable limit of error can be obtained, either by rinsing or by removal of packing.

e. All lower portions of vessels such as liquid blenders and storage tanks should be sloped (e.g., tanks may have conical or dished bottoms) to allow liquids to drain freely.

f. Equipment such as product and centrate collection vessels or chambers of centrifuges should be designed to contain material without loss by foaming, splatter, or formation of sprays in wet processes.

3. External Design

a. Visual access should be provided to all surfaces or spaces where material is likely to accumulate; alternatively, clearance should be provided to permit external use of nondestructive assay instruments or internal probes to detect the presence of SNM or to identify the location of residual material not visually accessible.[3]

b. Liquid transfer systems or vessels should have drains and valves installed at the lowest points to permit draining by gravity or other means. The stagnant volumes that may collect in drain lines and between tees and drain valves should be kept to a minimum. Transfer lines should have adequate slope to permit draining of process solutions after shutdown. If a pump is used, a drain equipped with a valve should be installed at the low point of the transfer line.

c. Equipment used to transfer solutions from storage tanks should be provided with adequate check valves to prevent siphoning or suction of process solutions into the steam or air supply lines. This equipment includes steam jets, steam lines, air lifts, gas purge lines, and vacuum relief valves.

d. If vacuum transfer of liquids is used, the vacuum pumps should be protected from corrosive vapors or SNM-containing liquids by suitable traps and filters. If other transfer methods such as liquid piston pumps are employed, these should also be protected.

e. Although seals and drain valves should be designed to be leaktight under normal conditions and to be free of crevices and cavities, provision should be made for the collection of material leaking through seals and valve seats when abnormal conditions exist.

f. Gravity transfer of liquid slurries from one vessel to another and of wet solids, centrates, and filtrates from centrifuges and filters should be used in preference to the use of transfer containers. If pumping of liquids or slurries is necessary, gas lifts should be used, provided the disengagement of gas does not result in excessive foaming or entrainment. Pumps should be designed to minimize cavities and stagnant volumes. All pumps should be mounted for maximum drainage and designed for minimal cavities and undrained volumes.

g. Equipment should be arranged so that connecting piping follows the shortest practical route with the fewest number of bends and fittings.

h. The piping network should be designed to allow free drainage to accumulation points.

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[3] Regulatory Guide 5.23, "In Situ Assay of Plutonium Residual Holdup," provides additional methods and procedures regarding measurements.

4. Design for Accomodating Cleanout

a. Equipment such as precipitators and digestors should be provided with access ports, removable covers, or removable sides to allow visual inspection of the internal surfaces.

b. Access ports or removable panels should be provided to allow cleaning of internal surfaces by appropriate methods such as brushing, vacuuming, washing, scraping, or rinsing to remove, dislodge, or dissolve SNM particles.

c. Equipment should be provided with fittings for connections for washdown and rinsing of internal surfaces of vessels and pipes. Steam, water, or appropriate chemical solutions should be used to dislodge, dissolve, or otherwise remove all particulate process material, residual liquid, and condensed vapors remaining on internal surfaces of the equipment. Quick-connect (-disconnect) couplings should be utilized in process lines where frequent cleanout is necessary.

d. Provisions should be made for flushing and draining and for removing and collecting rinsings in which SNM may be entrained or dissolved. Removal of material from centrifuge bowls, product collection chambers, and transfer lines should be facilitated by designs that permit disassembly. Also, distribution devices for flush solutions should be designed and arranged to allow flush solutions to contact the interior surfaces and cavities of the process equipment and of auxiliary devices inside the equipment. Flush lines to plutonium-containing vessels and equipment should be connected only to acidified solution sources.

e. Supplementary internal mechanical equipment not permanently mounted such as scrapers, agitators, atomizers, and rinsers should be capable of being disassembled and removed for cleaning and inspection.

f. Bottom outlets and drain plugs should be selectively located to facilitate draindown and cleanout. This is particularly important for vessels handling plutonium-containing solutions that can form polymeric compounds which may settle.

g. Wash or flush lines and spray rings should be connected at high points of transfer lines and piping networks or upper zones of interconnected vessels to permit flushing of accumulated solids.

h. Drain valves should be installed at low points in vessels and piping systems. Pumps for the piping network should be designed to facilitate disassembly for complete cleanout.

i. Interconnecting piping and pumps should be capable of being cleaned by flushing with clean drainings from storage or process vessels. Where necessary, separate flushing lines should be connected to transfer lines to assist in cleaning.

j. Storage vessels should be provided with separate bottom drain valves that permit their contents or wash solutions to be removed without affecting interconnected vessels.

k. Provisions (e.g., instrumentation) should be made to permit verification that all material has been removed from transfer lines.

l. Jets should be installed so as to completely empty vessels such as liquid storage tanks. To further decontaminate vessels, air and steam sparges should be installed as necessary.

m. The use of filters whose components must be disassembled for recovery of solids (for example, plate-and-frame filter presses) should be avoided.

n. Filter media should be removable or be capable of being backwashed in situ. Removable filter media should be treated by leaching or by combustion and leaching for the recovery and determination of SNM.

o. The composition of flush solutions for equipment containing residual plutonium should be controlled to avoid polymerization or precipitation (e.g., adequate acidification).