SLUDGE REMOVAL IN RADWASTE COLLECTION TANK

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ABSTRACT

The purpose of this paper is to present an efficient method to remotely remove settled sludge from nuclear power plant liquid waste tanks. Equipment will be utilized that is compatible with existing plant installed facilities. Radiation exposure to nuclear power plant operators will be kept as low as reasonably achievble (ALARA).

The present method of sludge removal utilizes manual techniques. Based on operating plant experience, manual tank cleaning is inefficient, expensive, and causes undesirable occupational radiation exposure and operational limitations.

Sludge samples were collected from different operating nuclear power plants and analyzed in Westinghouse facilities. Sludge characteristics such as chemical and radiochemical composition, suspended solids concentration, particle settling rates, angle of repose, etc., were determined. This information with additional feedback on plant waste processing system operating experience were utilized to determine the design basis of the sludge removal system.

The system major equipment consists of an eddy jet mixer, a waste liquid recirculation pump, a slurry transfer pump, a sludge separator and a sludge transfer pump. The system functions to eliminate the sludge layer remotely without excessive exposure and waste system disturbances.

INTRODUCTION AND BACKGROUND

Operating nuclear power plants whether pressurized water reactor (PWR), boiling water reactor (BWR), or other type must include in the plant design a liquid radwaste collection and processing system. This system is generally referred to as the waste processing system or WPS. The function of the WPS is to sufficiently treat the waste material so that it may be either recycled for reuse and/or discharged in accordance with plant and regulatory requirements. Liquid wastes that enter the WPS originate from many sources including various equipment drains, radiochemistry laboratory drains, and controlled-area floor drains. Each source contains specific contaminants including various radiochemicals, nonradiochemical and particulate material.

Typical process equipment contained in the WPS include tanks, pumps, heat exchangers, evaporators and demineralizers. A schematic representation of a PWR WPS is shown in Fig. 1. As shown, waste collection is the first major process requirement included in the system design. Prior to collection, piping installations may be utilized such that waste segregation is accomplished thus requiring many and varying size collection tanks. Segregation accomplishes separation of liquid wastes which may require different processing techniques to most efficiently accomplish the function of the WPS.

Liquid waste collection tanks utilized in operating nuclear power plants vary widely in name and design. They may be called waste collection tanks, waste holdup tanks, floor drain tanks, high conductivity collection tanks, laundry waste collection tanks, etc. The tank design is basically either horizontal or vertical but varies greatly

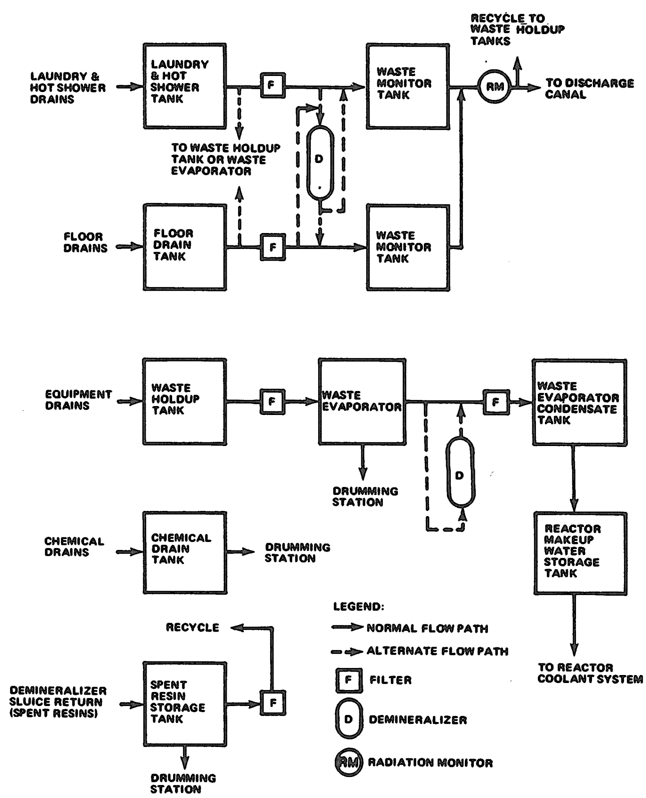


Fig. 1 Liquid Radioactive Waste Processing System

in size and dimension. Discharge nozzles may be side mounted or bottom mounted. Some vertical tanks may be designed with cone bottoms to facilitate particulate removal. However, this is not usually the case since cone bottom collection tanks, especially if large, are not space efficient. Most WPS primary collection vertical tanks are designed with flat bottoms and side mounted discharge nozzles with large manways near the tank bottom to facilitate periodic tank cleaning. The larger horizontally designed primary waste collection tanks also include manways near the tank bottoms for cleaning.

As anticipated by the system designers the waste collection tanks do require periodic cleaning to remove particulate material which had settled out over a period of time. Normally, this process could be accomplished manually without excessive radiation exposure to plant personnel. However, with the advent of "ALARA" it became practical to consider a system design that could remotely remove settled sludge from certain waste collection tanks installed in existing plants. ALARA means, as low as reasonably achievable, and is a regulatory authority requirement for implementation of any and all means available which can be shown to be justifiable for keeping nuclear plant operating personnel radiation exposure as low as is reasonably achievable, or ALARA.

Within an operating nuclear power plant there are numerous means for achieving ALARA. These include revised procedures, improved training, hardware modifications, shielding improvements and system design improvements such as the waste tank sludge removal system.

DESIGN BASIS

Based upon operating plant experience, waste tank sludge removal operations occur at varying frequencies depending upon individual designs and plant personnel considerations. These considerations include measured radiation levels in the occupied areas including inside of the tank itself. Generally, a sludge removal operation is carried out once or twice per year for each primary waste collection tank depending upon the nature and volume of waste entering the tank.

Tank cleanout operations may be let to outside contractors or performed by operating plant personnel. The methods are basically manual and may include procedures whereby maintenance crews physically enter the tanks with buckets and shovels, or stand close to open manways with suction devices to remove the settled sludge. These operations are very labor intensive, affect system availability, and result in operating personnel radiation exposure all of which contribute to increased operating costs.

The initial effort prior to the design of the waste tank sludge removal system was to determine if there was sufficient justification to support a development effort. Using information received from operating plant experience an estimate of potential cost savings was determined. Savings in materials and labor and an estimate in savings due to ALARA were included. Results for an example case are summarized in Table I.

TABLE I

Annual Cost Savings

Item	Basis	Cost Savings
10 Man-Rem	$5,000/Man Rem	$ 50,000
1724 Man Hours	$30/Hour	52,000
70 Filter Cartridges	$60/Unit	4,000
34 Drums Waste	$263/Drum	9,000
	Total	$115,000

The cost savings due to savings in man-rem (a measure of radiation exposure) was estimated to be 10 man-rem/year. The dollar worth for saving a man-rem is highly variable and for estimating purposes was taken as $5,000 per man-rem. This was generally accepted as a reasonable value for reducing occupational radiation exposure in an operating nuclear power plant. The factors considered in estimating the number of man-rem saving per year is also variable and quite plant specific. For this example the tasks required for manual entry into the tank were considered and included time savings associated with process operations, maintenance crews (for rigging lighting, breathing air, etc.), chemistry and health physics support and for handling and disposal of the final sludge containers. Additional savings resulted from waste products which would not be created by using the system. Although not every application would prove to be economical, sufficient justification existed to proceed with a system design. Table II outlines the principal system design bases.

TABLE II

Systems Design Bases

1. Remote Cleanout with Minimum Occupational Exposure (ALARA)
2. Minimum Backfit Impact
3. Sufficient Size for One Cleanup per Month per Plant
4. Capability to Remove 90% Settled Sludge
5. Operation Time Approximately 24 Hours/Month

In order to achieve the ALARA benefit, remote operations were required to minimize radiation exposure to plant personnel. For example, instead of requiring intense and local occupation of a relatively high radiation zone using multi-faceted labor skills, the process operator would simply realign valves and start and stop pumps.

Since most installations of the waste tank sludge removal system would be applied to operating nuclear power plants the design includes features to minimize backfit problems. The equipment would be supplied as a "kit", and preassembled where possible. A passive mixing device is utilized to reduce maintenance, and the overall system is kept small to minimize space requirements. The initial design goal was to achieve removal of 90% of the settled sludge within approximately one day of operation and not need to be repeated for at least one month.

SLUDGE CHARACTERISTICS

During the design process the waste tank sludge was characterized by analyzing samples obtained from operating nuclear power plants. The samples were analyzed for chemical and physical properties. Of primary interest in this design were such qualities as sludge settling rates and angle of repose. These and other sludge qualities were used as an aid in designing the waste tank sludge removal system. Table III gives typical ranges for the most significant physical and chemical properties of the sludge.

TABLE III

Results of Analysis		Plant A	Plant B
Iron, % as $Fe_3O_4 \cdot 4H_2O$		30	17
Silicon, % as SiO_2		15	35
Aluminum, % as AL_2O_3		1	2
All Other (Σ elements X 3)		20	20
Combustible Material		15	Not Analyzed
Water Content, %		90	86
pH		6.8	7.3
Radioactivity, MicroCi/g wet sludge		0.2	1.7
		(90% is CO-60)	
Settling Rate,	10 min.	20	86
(% by weight settling	30 min.	98	99.9
through 40 cm of water)	60 min.	99.9	99.9
Angle of Repose (wet sludge under water)		36°	40°
Specific Gravity (dry sludge)		6	4
Particle Size Distribution, % by Wt. (determined by converting particle size by number to particle size by mass.[1])			
0-5 Micron		17	17
5-10 Micron		15	15
10-50 Micron		53	53
50-100 Micron		15	15

The major portion of the sludge material appears as a solid smooth mass with a dark color having a consistency of mud or muck. Based on interviews with plant personnel the sludge may contain particulate material generated from water lancing operations during equipment maintenance, general dirt from the floor, welding rod slag, concrete dust from chipping and grinding operations, cement dust from solid waste processing operations, strands from mop heads, dust from the air, fibers from paper products, and corrosion and erossion products from various plant equipment.

SYSTEM DESIGN

The waste tank sludge removal system is shown schematically in Fig. 2. The system consists of an eddy jet mixer, a waste liquid recirculation pump, a slurry transfer pump, a sludge separator and a sludge transfer pump. The system is designed to remotely eliminate the sludge layer in the tank without excessive occupational radiation exposure to plant operators and unnecessary perturbation in the plant existing liquid waste processing system.

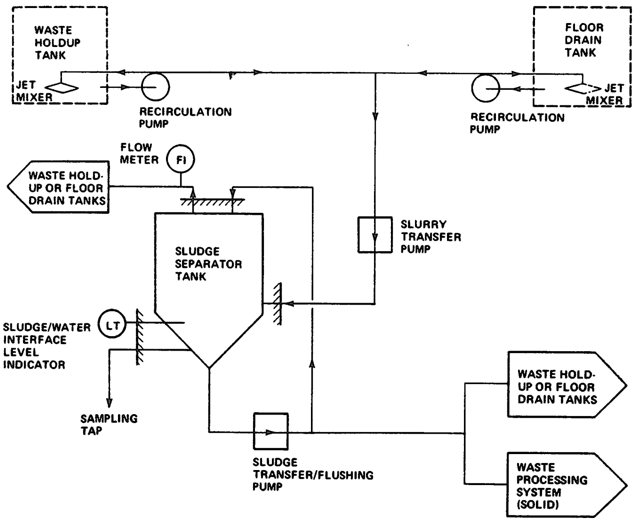


Fig. 2 Westinghouse Waste Tank Sludge Removal System

The system's function can be separated into the following operations:

1. The settled sludge is resuspended in the waste collection tank through a vigorous mixing process.
2. The resulting waste tank slurry is treated for sludge/water separation.
3. The accumulated sludge is transferred to various solid waste handling system for final disposal.

An evaluation was made to select the proper equipment to satisfy the system functional requirements. In the following sections, each operation is discussed with more details.

Sludge Resuspension

The purpose of this operation is two-fold. First, to reslurry the settled sludge on the bottom of the waste tank, and second, to keep the solid particulate material in suspension while the separation process is performed. To achieve these objectives, various equipment was evaluated including top-entry agitators, side-entry agitators and jet mixers. The jet mixer was selected for its following advantages.

1. Proven technology
2. Adequate design information
3. Easy to backfit
4. Simple structural support required
5. No baffles needed inside the waste tank
6. No moving part in the waste tank
7. Not susceptible to forming a vortex and thus reducing air entrainment and subsequent foaming problem

The basic principle of jet mixing is to create fluid motion by pumping the fluid through nozzles within the tanks. An artist's conception of this operation is shown on Fig. 3. A centrifugal pump is used to force fluid through eductor nozzles to generate high velocity jets entraining additional water in the tanks resulting in a higher total flow. This results in a fluid motion of combined shear and circulation to achieve the mixing action within the tanks.

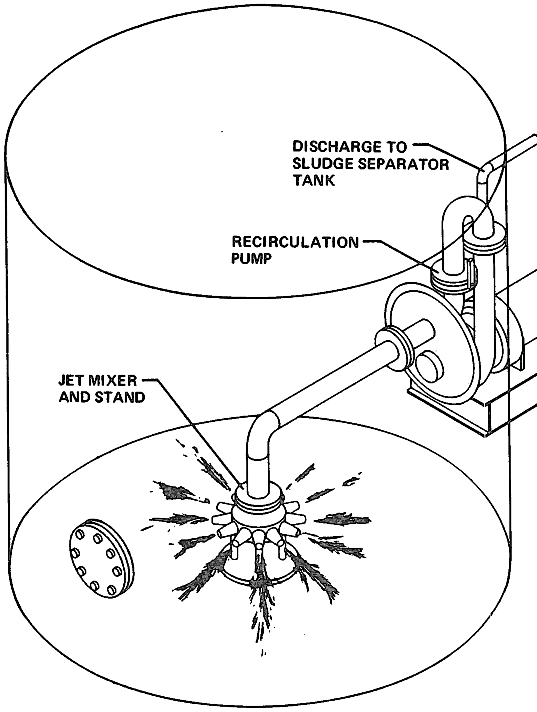


Fig. 3 Jet Mixing Operation in Waste Collection Tank

A step-by-step procedures to size and evaluate jet mixing for this particular application was performed.[2] From the results of sample analyses, the settling rate distribution of the sludge was determined. For conservatism 10 times the largest particle settling rate of the sludge material was used to estimate the fluid velocity required for sludge resuspension. An equation from the dimensionless analysis of the experimental results is used as follows:[3]

$$V_b = V_r \cdot C_d \left(\frac{d_o}{V_o}\right) \left(\frac{R}{d_o}\right)^{3/2} \left(\frac{Z}{d_o}\right)^{1/2} \quad \text{eq.(1)}$$

Where:

V_b = Volume of the fluid in the tank, M^3

V_r = Volumetric flow rate within the tank, M^3/sec

C_d = Coefficient of mixing

$= \frac{2}{\text{Jets per mixer}} (2.08 - 0.1968H)$

H = Jet submegence, or height of water above jet mixer, M

d_o = Diameter of one jet nozzle (outer), M

V_o = Discharge velocity at nozzle outlet, M/sec

R = Radius of tank, M

Z = Side water depth, M

Also $$V_r = A \cdot \bar{V} \quad \text{eq.(2)}$$

Where:

A = Mean area perpendicular to the flow, M^2

$\bar{V}$ = Resuspension fluid velocity, M/sec

From eg. (1) and (2), the discharge velocity, V_o, is obtained as 0.44 M/sec

Based on a system with 2.54 cm outer nozzle diameter and eight jets, the volumetric flow rate of the jet mixer was determined to be 76 l/sec. Because part of the jet mixer flow is entrained by the pumped flow, the actual capacity for the pump is approximately half of the total jet mixer flow.

Sludge/Water Separation

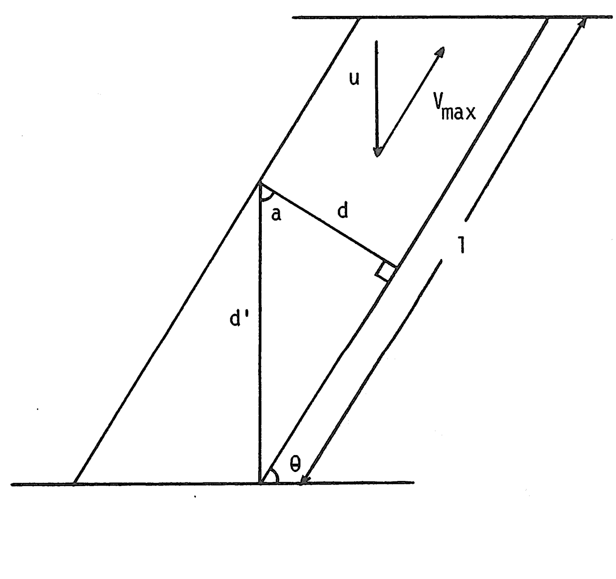
The purpose of this operation is to separate the sludge out of the resulting slurry. Various types of equipment were evaluated for their performance and suitability for this application including various types of filters, centrifuges, and inclined tube settlers. An incline tube settling tank was chosen for the following advantages:

1. Well known process parameters
2. Reasonable ease of maintenance
3. Proven technology
4. Sufficient settling efficiency
5. Space saving
6. Easy to backfit

The sludge separator tank consists of an inclined tube bundle which is installed in the upper section of the tank. The inclined tube design is to aid in the sludge settling operation by reduction of flow velocity and settling distance within the tube bundle. Also, the tube settler is inclined at an angle in excess of the angle of repose determined for the sludge. This causes the settling sludge to slide down the tube and collect in the cone bottom of the sludge separator tank.[4]

In such cases, the slurry feed stream enters the lower section of the separator tank below the tube settlers. The sludge settles out and collects at the bottom of tank, and clearer fluid leaves the top of the separator tank.

The primary design equation of the sludge separator tank originates from the particle settling behavior within the tube. The tube can be expressed as follows:



Where:

l = length of the tube settler, M

d = diameter of the settler tube, M

u = settling velocity of the particle, M/sec

V_{max} = maximum velocity of the fluid within the tube, M/sec

A geometric relationship can be obtained as

$$\frac{l}{d'} = \frac{V_{max}}{u}$$

Also $a = \theta$ and $d' = \frac{d}{\cos\theta}$

$$l \cdot \cos\theta = \frac{V_{max}}{u}$$

$$V_{max} = \frac{l\ u \cos\theta}{d} \qquad \text{eq.(3)}$$

The fluid velocity in each tube can be expressed as the flow rate (Q_{max}) to the separtor tank.

$$V_{max} = \frac{Q_{max}}{AN}$$

Where:

A = cross-sectional area of the tube, M^2

N = number of tubes per tank

Eq. (3) can then be expressed as

$$Q_{max} = \frac{l\ u \cos\theta\ AN}{d} \qquad \text{eq.(4)}$$

This is the design equation for the inclined tube settling tank.

For typical sludge settling rates Q_{max} may vary from 4 to 200 l/sec.

Sludge Transfer/Disposal

After the sludge settles on the bottom of the inclined tube settling tank, it is transferred to the nuclear power plant existing solid waste processing system for final disposal. In order to achieve a smooth and efficient transfer of the sludge, an air-operated double diaphragm pump is used. This pump is selected for its following advantages:

1. Can handle suspended solids up to near pipe size.
2. Can run dry indefinitely with no damage.
3. Can run deadheaded (discharge closed) indefinitely without damage.
4. Does not require bypass installations or pressure relief devices.
5. Self-priming.
6. Flow rate can be adjusted by varing pump speed with various air pressure without additional equipment.

To determine the required head for transferring the sludge from the separator tank to the solid waste processing system, the following equations were used.[5]

First the Froude Number for the terminal settling velocity (Fr*) is determined.

$$Fr^* = \frac{u}{\sqrt{gd\ (P_\rho/P_\ell - 1)}}$$

Where:

u = particle settling velocity, cm/sec

g = gravitational constant

d = diameter of pipe used for transferring sludge, cm

P_ρ = specific gravity of the particle

P_ℓ = specific gravity of the liquid

Also Fr_ρ (particle's Froude Number) is determined.

$$Fr_\rho = \frac{v}{\sqrt{gd_\rho\ (P_\rho/P_\ell - 1)}}$$

Where:

v = velocity of slurry, cm/sec

d_ρ = diameter of the particle, cm

From the design information and data

$Fr^* = 6.7 \times 10^{-4}$

and $Fr_\rho = 23.7$

From Fig. 1 in Ref. (3)

$Vrel/_V = 6 \times 10^{-3}$ with this value,

Xo, a dimensionless pressure drop parameter, is then obtained as 3.6×10^{-5}

With this information, the pressure drop can be obtained as

$$\Delta P_\rho/_L = Xo \cdot Cv \cdot (P_\rho - P_\ell)\ g\ (v/_u)^2$$

Where:

Cv = fraction of solid/liquid

L = transfer distance, M

The final required head is obtained as 7 kg/cm^2 for 152M of transfer distance.

CONCLUSIONS

The installation of a waste collection tank sludge removal system will achieve an efficient and remote removal of radioactive sludge with the benefits of lower occupational radiation exposure, enhanced waste processing system operability, equipment replacement cost and manpower savings.

Lower Occupational Radiation Exposure

The system is designed to remove and transfer the radioactive sludge remotely for final disposal, thereby reducing excessive occupational radiation exposure for the plant operators in performing the manual sludge removal operation. Also, by cleaning up the waste collection tank more frequently, the radiation level in the vicinity of the tanks is greatly reduced.

Enhancement of Waste Processing System Operability

The sludge removal system can be readily backfitted to the existing nuclear power plant waste processing system with minimum disturbances. Also, with the sludge removal system in operation, it will reduce the plant waste processing system down time required for maintenance work, such as the lengthy manual tank cleaning and filter/demineralizer media changeout operations. From the aforementioned improvements in the operation of plant waste processing system, the operability and availability of the waste processing system are increased.

Equipment Replacement Cost Savings

By periodically removing the accumulated sludge from the waste tanks, the sludge removal system will eliminate the contamination and frequent plugging of the downstream filters and demineralizers due to the sludge carryover from the waste collection tanks. The replacement cost of these "changeouts" of the filter cartridges and demineralizer resins can be saved.

Plant Operating Manpower Savings

The manual tank cleaning/sludge removal operation is a time consuming process. The waste collection tank sludge removal system is designed with high system operational efficiency and effectiveness. It will increase the plant operator's productivity and result in manpower savings.

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