U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

REGULATORY GUIDE 5.48

DESIGN CONSIDERATIONS SYSTEMS FOR MEASURING THE MASS OF LIQUIDS

A. INTRODUCTION

Section 70.58, "Fundamental Nuclear Material Controls," of 10 CFR Part 70, "Special Nuclear Material," requires that the quantity of special nuclear material (SNM) on inventory be known on the basis of measurement at the beginning and end of each material balance interval. Section 70.51 of 10 CFR Part 70 requires that all SNM added to and removed from processing during that interval be measured. Section 70.58 also requires that all random and systematic errors associated with such measurements be controlled so that the limit of error of material unaccounted for (LEMUF) at the end of any material balance interval does not exceed the amount specified in the regulation.

This regulatory guide pertains to design considerations for methods of measuring the mass of liquid contained in a vessel and identifies those design considerations which the NRC staff considers to be adequate for minimizing the error associated with that measurement. Equipment and procedures for obtaining liquid samples are the subject of another regulatory guide, which is currently in preparation.

B. DISCUSSION

Measurement of the SNM content of a vessel containing a homogeneous liquid solution consists of three principal operations: (1) measurement of liquid mass (either by weighing directly or by measuring the volume, temperature, and specific gravity); (2) obtaining a representative sample of the vessel contents; and (3) assay of the sample to determine the SNM concentration in terms of unit weight or unit volume.

This guide deals with measurement activities that are affected by vessel design. Proper attention to design makes possible more accurate measurement of the solution bulk. It also improves the ease of achieving accurate bulk measurements and obtaining representative samples. The determination of chemical and isotopic concentrations in samples by traditional analytical techniques is independent of vessel design, and chemical and isotopic assay are not discussed in this guide.

1. Bulk Measurement of Liquid

a. Measurement of Weight

Determination of solution bulk by weighing is advantageous because this makes it unnecessary to measure the temperature and specific gravity of the solution, eliminating random and systematic errors inherent in measuring temperature and specific gravity and avoiding the possibility of mistakes in making temperature corrections. Another advantage of determining solution bulk by weight is that there is no requirement for dimensional uniformity within the vessel to achieve calibration linearity.

A disadvantage of weighing is that rigid piping connected to the vessel can produce mechanical stresses due to deflection and thermal expansion. These stresses can affect the indicated weight. Weighing systems of the null-balance type, which restore the vessel to a reference position, can minimize the effect of stress caused by deflection of the vessel with increasing weight. However, such systems do not compensate for thermal expansion. Where disconnects are permissible and the number of connections is small enough to make disconnection feasible, the vessel may be disconnected from the piping during a weight determination to eliminate this effect. Otherwise, temperatures are held constant or an additional correction is included.

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In vessels equipped with heating-cooling jackets, errors in solution weight measurement can occur if the weight of fluid in the jacket varies. This is more likely to be a problem when steam rather than a liquid heat-transfer medium is used for heating. If a liquid heat-transfer medium is used, the problem may be less severe in a vessel with internal coils than in a vessel with an external jacket.

Weighing a vessel containing SNM can be done by mounting the vessel on an industrial platform scale or by placing hydraulic load cells under the vessel supports. Industrial weighbeam balances and pendulum balances have capacities of tens of thousands of kilograms and accuracies of 0.1%.[1,2] Under carefully controlled conditions, an accuracy better than 0.1% can be achieved; 14,000-kg cylinders of uranium hexafluoride are routinely weighed with an accuracy of 0.01%. Pendulum balances indicate weight without requiring the manipulation of standard weights and thus are more readily adapted for remote reading and automatic printout.

Industrial use of weighbeam or pendulum balances has been largely limited to applications where the vessel is accessible for maintenance and adjustment. Where radiation levels preclude such access, direct weighing can be accomplished by supporting the vessel on hydraulic load cells or by applying electric resistance-wire strain gages to the vessel supports.

Hydraulic load cells have a capacity of about 25,000 kg.[2] An accuracy of 0.1% can be achieved.[3] The load on all the supports can be easily combined and can be read at any convenient remote location. The readings are sensitive to temperature, but substantial temperature correction is possible.

The feasibility of using hydraulic load cells to measure the weight of process feed was studied at the Idaho Chemical Processing Plant.[3] Because the installation was on an existing vessel that was not adapted to the purpose, the tests were inconclusive. However, valuable insight was gained into desirable design features for such an installation.

Electric strain gages are highly sensitive and have a capacity of 200,000 kg. Strain-gage readings are influenced by temperature, but this effect can be readily compensated for. Their accuracy approaches that for hydraulic load cells, but they are expensive and relatively fragile; hence, they are not normally used for the weighing of vessels containing SNM.

b. Measurement of Volume, Temperature, and Specific Gravity

Bulk measurement of volume is usually accomplished indirectly: the liquid level is measured directly; then a prior calibration of liquid level vs. volume is applied. Removals or additions to process can be accurately measured by filling a precisely calibrated tank volume to overflowing and then transferring the known increment of volume to the process. Alternatively, liquid level can be measured by any of several devices: purged dip tubes, sight glass, or other types of level sensors.

Pairs of pneumatic dip tubes are used in high radiation fields because of their simplicity. The opening of one of the tubes is submerged, and the opening of the other is in the vapor space above the liquid. The pressure difference between the two tubes while air is passed through the tubes at the same rate is proportional to the product of the height of liquid above the opening of the submerged tube and the density of the liquid. This pressure difference is sometimes called the "weight factor." For vessels having a uniform cross section, the weight factor is directly related to the mass of liquid above the submerged tube opening.

Specific gravity can be measured by using a pair of dip tubes, the ends of which are submerged to different but known depths. However, the results are usually less reliable for accountability purposes than can be obtained by measuring the specific gravity of a representative sample withdrawn for chemical and isotopic analysis. The liquid level in a vessel is the quotient of the weight factor, expressed in suitable units, divided by the specific gravity of the liquid. When properly designed and installed,[4] a pair of purged dip tubes can measure liquid level with a precision of 0.6% of full scale. Accuracies of 0.1% to 0.2% can be achieved in a calibrated tank under carefully controlled conditions.

A sight glass gives a positive reading of liquid level, but is subject to breakage (which could result in the spread of contamination). Sensing of liquid level can be done by other means, such as hydrometer-type floats or ultrasonic ranging. The resultant accuracy is generally not adequate for accountability measurements, however.

In the design of vessels for volume measurement, the systematic error associated with the existence of a liquid heel below the lowest limit of the measuring device can be a serious problem. Heel uncertainty is not important for throughput measurements, where differences in liquid level are measured and the heel can be accounted for in the measurements. For measurements of absolute quantities during an inventory, however, the error introduced by the heel volume can constitute much of the measurement error. The complexity of volumetric calibration is greater when the vessel cross section varies with height, as may result if there are components (impellers, baffles, heat-cooling coils, etc.) within the vessel. On the other hand, effective mixing to obtain homogeneity generally requires some obstructions such as spargers or impellers and baffles. Hence, the designer seeks the trade-off features that are the most desirable for each application.

Other drawbacks to determining bulk contents by measuring volume are the complications introduced by temperature changes and the errors contributed in making the necessary temperature corrections. Most vessels expand at elevated temperatures, although slab tanks may decrease in volume with increasing temperature if the sides are constrained to buckle inward.

Not only does the vessel volume change with temperature, but the contained solution also expands when heated. Therefore, each liquid-level measurement has associated with it the temperature at which the measurement is made. Furthermore, laboratory determinations of specific gravity and SNM concentration are frequently made at temperatures other than those at which the bulk volume was measured and at which aliquots were taken. Therefore, the temperatures at which aliquots are taken should be recorded. Unless the uncertainties associated with temperature measurements are held within tolerable bounds and all temperature corrections are properly made, the accuracy of the bulk volume measurement will be poor.

2. Vessel Design Features Pertainent to Obtaining a Representative Sample*

a. Mixing of Vessel Contents

To ensure a liquid solution having uniform composition, vessel contents can be mixed by gas spargers, by mechanical impellers, or by external recirculation (pumping the solution out and back in).

Gas spargers are relatively ineffective, lengthy sparging being required to bring about uniformity of the tank contents. They also increase the load on the offgas filters. However, they are inexpensive and require little or no maintenance. Spargers are more effective in tall, narrow tanks than in short, wide ones. The optimum gas flow rate is about 0.75 m^3/sec (1.3 cfm) per square foot of tank cross section.[4]

Mechanical agitators (motor-driven impellers) provide positive mixing action and are widely used where maintenance is possible.

b. Obstacles to Effective Mixing

Precise measurement requires that the composition and temperature of the solution to be measured be completely uniform before the solution is sampled. Unfortunately for this purpose, vessels containing solutions of SNM are often, for criticality prevention, made in the shape of slender cylinders, thin slabs, or thin annuli—shapes that are not suitable for effective mixing. Cylindrical vessels whose axes are horizontal or nearly so are especially poorly adapted to efficient mixing.[5] If a slab or cylinder does not have adequate storage capacity for a given volume of liquid and if several such slabs or cylinders are manifolded in parallel, the problem is further aggravated. When several such vessels are manifolded in parallel, uniformity of the contents of all of the vessels is difficult to achieve.

Boron-containing raschig rings used as tank filters to prevent criticality are another impediment to effective mixing.

*Recommended procedures and equipment for taking liquid samples are contained in another regulatory guide (in preparation) in this series.

C. REGULATORY POSITION

This section provides guidance for vessel design to facilitate the accurate measurement of contained SNM.

1. The following guidelines are of general applicability to the design of vessels in which accountability measurements are to be made.

a. The vessel design should take into account the elements of random and systematic error contributed by each component of the bulk measurement and sampling operations and should minimize the overall measurement error resulting therefrom.

b. The vessel design should consider the means for standardizing and calibrating each measurement operation* and should provide for continuing quality assurance of the measurement system during plant operation.

c. To arrive at the overall vessel design, the designer should integrate the bulk measurement and sampling operations with all process requirements and with any additional constraints imposed by considerations of safety and criticality prevention.

d. Piping connected to measurement vessels should be designed to drain reproducibly and, if possible, to drain quickly.

e. The design should require that only with the measurement vessel and its contents at rest should measurements be made.

2. The following guidelines apply to vessels whose bulk content is determined by weighing the vessel and its contents.

a. The tank should be installed in such a manner that no variable extraneous loads are imposed as a result of mechanical or thermal stresses in attached piping. Systems having essentially zero deflection (null balance) should be considered as a means for reducing stress effects from connecting piping. Even with a null-balance system, the vessels should be protected from thermal and mechanical forces. Care should be taken to minimize rigidity of piping to weighing vessels, as by the use of properly supported flexible metal lines or small-diameter piping with reasonably long horizontal runs. To minimize thermal stresses, the design should provide for constant or reproducible temperatures in the connecting piping insofar as possible.

b. Convolutions in flexible metal lines and any bends, incorporated to minimize piping rigidity, should be oriented so that the piping drains freely.

*See, when published, a regulatory guide (in preparation), "Measurement Control Program for Special Nuclear Material Accounting." See also ANSI Standards N15.18, "Mass Calibration Techniques for Nuclear Materials Control," and N15.19, "Volume Calibration Techniques for Nuclear Materials Control" (both in preparation).

c. Mechanical linkages between the weighing device and readout mechanism should be minimized, and measurements should be recorded by means of remote printout, particularly if the alternative is a series of levers to transfer the reading from the vessel to the measuring location. In any case, digital printout is recommended in order to avoid parallax errors, misreading, and recording blunders. If an integrated computerized inventory system is used, the weight should be recorded by the computer.

d. Any mechanical linkages used in the load transmission system should be lubricated and protected from corrosion or the introduction of dust.

e. If a heating-cooling jacket is needed on the solution tank, the piping should be designed so that either the jacket can be filled to a constant volume or it can be drained completely to eliminate errors caused by varying weights of fluid in the jacket.

f. The weighing system should be designed so that initial calibration and periodic recalibration can be done in place. This requires that the system have the capability of adding precisely known weights to the vessel over the entire measurement range.

g. Since vessels mounted on weighing systems are not supported against shocks or earthquakes, appropriate use should be made of staybars or limit stops.

3. The following guidelines apply to vessels whose bulk content is determined by measuring volume, temperature, and specific gravity.

a. The vessel should be calibrated by liquid additions in such a manner that the total error of the bulk volume calibration at any liquid level is within the accuracy appropriate to its overall contribution to the limit of error of material unaccounted for. (Greater accuracy in calibration is normally required for vessels containing feed or product solutions than for vessels that contain waste solutions.) The calibration should include a sufficient number of liquid levels to bracket closely all discontinuities or fluctuations in cross-sectional area.

b. The following features in the design of a vessel enhance the capability of obtaining overall measurement errors that are acceptable:

(1) The vessel should be a right circular cylinder, with the principal axis oriented vertically. Vessels having a slab configuration should be avoided unless special provisions are made for ensuring uniformity of cross section with height.

(2) The ratio of vessel height to horizontal cross-sectional area should be such that the product of the cross-sectional area and the smallest increment of liquid level that can be measured does not exceed the required volume sensitivity.

(3) For cylindrical vessels fabricated of flat stock, care should be taken to ensure that the circumference is uniform with cylinder length. Anomalous circumference variations in cylindrical vessels should not exceed 0.05 percent between calibration points.

(4) The vessel interior should be as free as possible of coils, baffles, and other objects that interfere with the linearity of the calibration.

(5) When mixing baffles or other internal devices are essential to the design, such baffles or devices should have a uniform cross section throughout the range where measurements are normally made. Two or three such constant-area regions are permissible in a vessel, provided the transition areas are outside normal operating regions.

c. Provision should be made for periodic in situ recalibration of vessels by the addition of precisely known quantities of liquid.[6]

d. For vessels in which absolute quantities are measured, provision should be made for keeping the heel volume constant, and the heel volume should be kept small. To the extent feasible, the heel volume ordinarily should not exceed 1% of the nominal volume of liquid measured.

e. Whether mixing is done by sparging or by an impeller, measurement of the liquid level should be done when the vessel contents are quiescent in order to get an accurate reading. During measurement, recirculating samplers should be turned off and the gas flow to the dip tubes should be the minimum practical.

f. If pneumatic dip tubes are used for determining liquid level, care should be taken in selecting the diameter of the dip tubes, the length of gas supply lines, the shape of the open end (bubbler orifice), the fixing of the dip tubes in the tank, and the materials of construction; also, equalization of flow rates in any pair of dip tubes[7] should be provided.

The dip tubes should be installed so that the opening of one of them is located above the highest level reached by the liquid and any foam formed on top of the liquid. The lower dip tube should be located as low as practicable.

The lower tube should be rigid and should be supported to resist bending. The openings at the ends of the tubes and the pneumatic supply lines should be designed so that pressure drop between tube ends and the point where pressure is measured does not exceed about 3 pascals (0.01 in. H_2O) for the flow rated used. Pneumatic supply lines should be leak-tight.

To provide a means for measuring the specific gravity of the liquid, an additional dip tube may be installed with its open end in the liquid a fixed distance above the lower tube. This measurement can be used to confirm any specific gravity determinations on a sample of the liquid contents.

The type of readout, manometer or transducer, should be evaluated for each dip-tube application. A manometer gives a more direct measurement. Also, a precision manometer read by a careful, trained operator gives better accuracy than can be obtained with transducers routinely associated with process instrumentation. However, a precision pressure transducer can give readings that are just as accurate—without the need for a trained operator. Furthermore, the transducer readings can be transmitted directly to a data collection system, thereby avoiding reading errors entirely. However, transducers should be calibrated frequently. For either type of instrument, the design should provide for in-place calibration.

If an integrated computerized inventory system is used, the differential pressures and the equivalent solution bulk should be recorded by the computer.

g. The weight factor should not be used without temperature correction unless it can be demonstrated that any change in specific gravity is exactly offset by a change in liquid depth. This condition will occur only if the vessel cross section is constant with changing temperature or if the changes encountered in vessel volume or temperature are small enough that thermal expansion of the vessel walls can be neglected.

h. If liquid level is measured by means of a sight glass, care should be taken to ensure that the density of the liquid in the sight glass is the same as the density of the liquid within the vessel. The scale attached to the sight glass should be of noncorrosive material and should have a low coefficient of thermal expansion; provision should be made for its calibration. The designer should also ensure that the sight glass will measure all liquid levels to be encountered during its use. Protection should be provided against breakage of the sight glass.

i. If the use of several thin slabs or long cylinders in parallel is necessitated by criticality considerations, provision should be made for ensuring the homogeneity of the contents of all of the vessels. Alternatively, provision should be made for ensuring that solution cannot leak from one vessel to another and that solution intended for a given vessel cannot leak (e.g., through a valve) to another vessel in the bank. Provision should also be made for measuring the volume of liquid in each vessel, and each vessel in the bank should be capable of being sampled independently.

4. The following guidelines apply to design considerations pertaining to mixing of vessel contents to ensure the obtaining of a representative sample.

a. A single gas sparger may be used for vessels up to 3 m (10 ft) in diameter; larger vessels should have more than one sparger.

b. Use of raschig rings in vessels in which accountability measurements are to be made should be avoided wherever possible. Other means of preventing criticality should be considered for such vessels. If raschig rings are used, precautions should be taken to ensure thorough mixing and completeness of transfer. Because raschig rings tend to compact during use, the designer should consider the need for more frequent calibration of vessels filled with raschig rings.

c. If mixing is done by external recirculation and if the recirculating pump and piping are not dedicated to the measurement vessel, care should be exercised that the solution to be measured is completely returned to the measuring vessel and that none escapes elsewhere in the process. In any case, the returning solution should be distributed in the vessel volume—for example, by spraying.

D. IMPLEMENTATION

This section provides information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which the applicant proposes an alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used in the evaluation of submittals in connection with special nuclear material license, operating license, or construction permit applications docketed after June 1, 1975.

If an applicant whose application for a special nuclear material license, an operating license, or a construction permit is docketed on or before June 1, 1975, wishes to use this regulatory guide in developing submittals for applications, the pertinent portions of the application will be evaluated on the basis of this guide.

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5. J. E. Harrell, "Mixing and Sampling Enriched U-235 Fluids in Cylindrical Storage Containers," USAEC Report Y-1561, January 17, 1967.

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