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ER-80208

LARGE STORAGE TANK MASS DETERMINATION STUDY

For Second Quarter Reporting Period

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PROGRESS DURING PAST QUARTER

During the past quarter, the study phase was completed and a design approach selected. Optical absorption, neutron moderation, gamma absorption and backscatter, and beta absorption and backscatter were considered. The results of these studies will be documented in a separate report.

The method selected is based on gamma ray absorption. The gamma ray sources and detectors are arranged in such a way that the integral

$$m = \int_V \rho dv$$

is evaluated by a sampling technique. The technique employed results in moderate source strength requirements.

A detailed error analysis for the selected method has been made, and a preliminary determination of the system parameters from this analysis has been completed.

Radiation safety and source handling problems have been considered. The details of the system description, parameter selection, and radiation safety precautions are discussed in detail in this report.

To summarize the results, the preliminary system specifications are:

Accuracy:	0.25% of full scale
Effective Sampling Time:	7.5 seconds
Equivalent Time Constant:	3.75 seconds

(RC circuit time constant
(BW = $\frac{1}{2\pi(3.75)}$ = .04 cps 3 db pt.)

Detectors:	2" dia. x 2" NaI(Tl) scintillators
Source:	Ta^{182}
Source Strength:	640 mc each
Number of Sources:	5
Total Activity:	3.2 curies

WORK SCHEDULE DURING NEXT PERIOD

During the next period the subsystem and component specifications will be completed and presented to MSFC for approval. In addition, the various approaches which were studied and rejected will be documented. Upon approval of the system preliminary design, final design and fabrication will commence.

1.0 SYSTEM DESCRIPTION

1.1 General

Figure 1 depicts the system concept. Collimated sources are placed on one end of the tank and detectors on the opposite end. The contents of the tank are always between the sources and detectors. Using the nomenclature of Table 1, the output frequency f_i of the i^{th} detector is given by:

$$f_i = f_o \, e^{-\mu \int_o^y \rho dy_i} \tag{1}$$

This may also be written in the form:

$$\log \frac{f_o}{f_i} = \mu \int_o^y \rho dy_i \tag{2}$$

If there are n detectors, and the logarithms of the output frequency ratios are multiplied by ΔA_i where

$$\Delta A_i = \Delta A_j = \frac{A_T}{n} \tag{3}$$

then the sum of the quantities so obtained is:

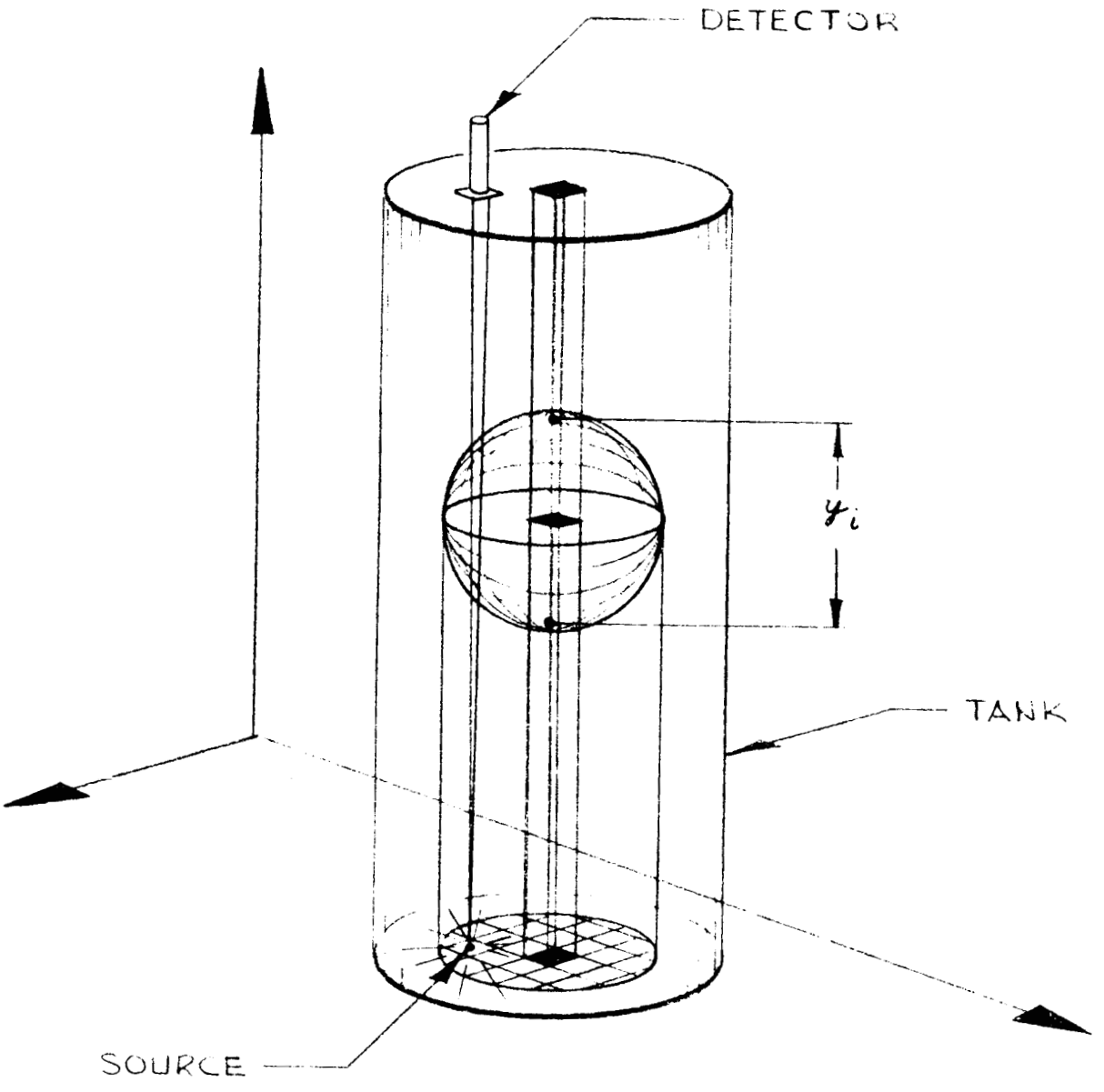
$$\frac{A_T}{\mu n} \sum_{i=1}^{n} \log \frac{f_o}{f_i} = \sum_{i=1}^{n} \Delta A_i \int_o^y \rho dy_i \tag{4}$$

By definition of the volume integral, it can be seen that:

$$\frac{A_T}{\mu n} \sum_{i=1}^{n} \log \frac{f_o}{f_i} = \iiint_V \rho dv + \varepsilon \tag{5}$$

where:

$$\begin{array}{l} \text{Lim } \varepsilon = 0 \\ \Delta A \to 0 \\ n_i \to \infty \end{array} \tag{6}$$



System Concept

FIGURE 1

TABLE 1

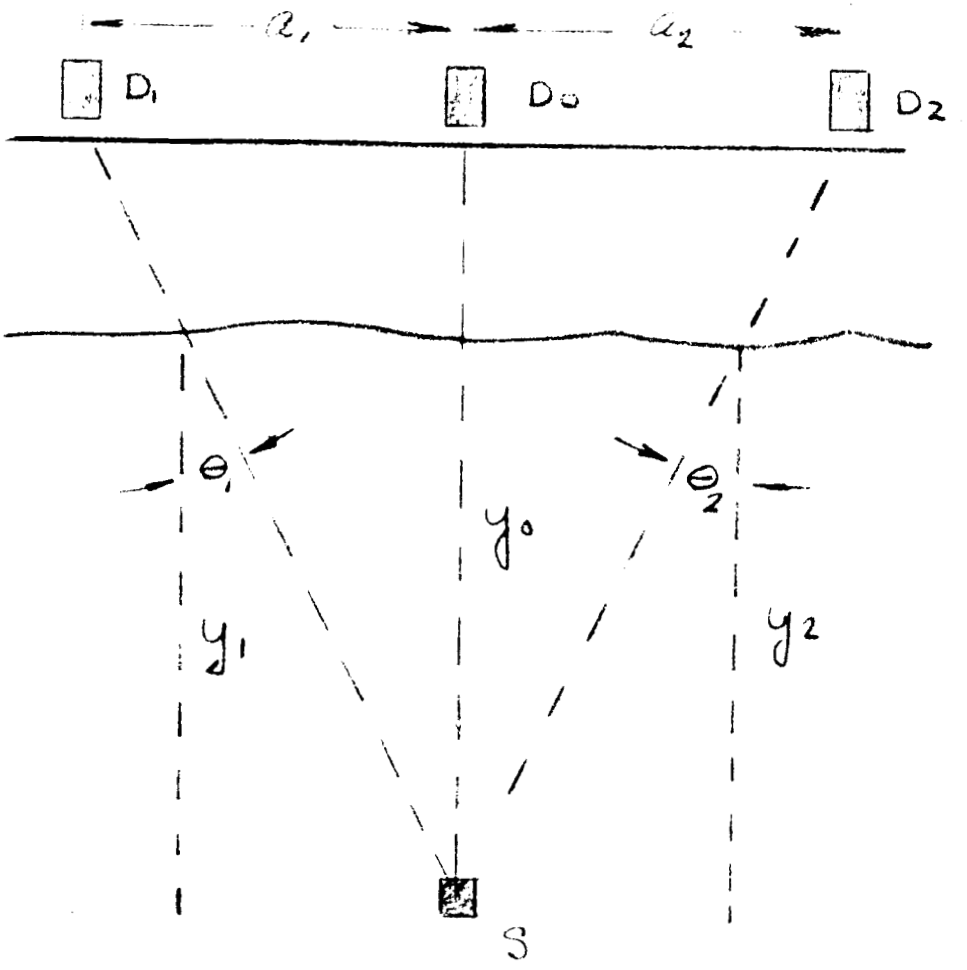
f_i =	output frequency of i^{th} detector	(sec^{-1})
f_o =	output frequency of any detector where its column is empty	(sec^{-1})
μ =	mass absorption coefficient	($cm^2\ gm^{-1}$)
ρ =	density	($gm\ cm^{-3}$)
n =	number of detectors used	-
L =	tank length	
ε =	error in approximation of volume integral	-
A_T =	total cross section area of tank	(cm^2)

The term ϵ in equation (5) is an error which is diminished as the number of samples is increased. The magnitude of ϵ for a given n is dependent upon the distribution of the tank contents within the tank. A general expression for ϵ cannot be given unless a specific distribution can be assumed. In cases where this is possible, the existence of ϵ is a trivial matter since removal of the error is then only a matter of calibration.

Thus, for the case at hand, ϵ can be determined for each slosh mode (if necessary). For extension to zero g (where the assumptions regarding the fluid distribution must be less realistic) it may be necessary to increase n. With solid state detectors, n values of 100 or more can be realized. This will certainly reduce ϵ to tolerable values without regard to fluid distribution within the tank.

1.2 Number of Sources Required

It is not necessary to have one source for each sample, as shown in Figure 1. It is only necessary to assure that no detector sees more than one source. Thus n may be increased without increasing the number of sources, and hence the total amount of radioactivity. The situation is made clear by Figure 2, in which three values of y are determined by one source. Referring to Figure 2, detector D_1 is actually sampling the height at y_1, D_2 that at y_2, and D_o that at y_o. To obtain y_1 from the output reading of D_1 one uses the relation:



Multiple Samples with Single Source

FIGURE 2

$$f_i = f_o \, e^{-\mu \rho y_1 \sec \theta_1} \tag{7}$$

θ is fixed by the system geometry:

$$\theta_i = \tan^{-1} \frac{L}{a_i} \tag{8}$$

where L is the tank height. Since θ_i is constant, it merely affects the scale factor associated with the i^{th} detector.

The propagation of errors in this system was derived in ER-80206.

2.0 SYSTEM PARAMETER DETERMINATION

In Report No. ER-80206 it was shown that the system error may be expressed in terms of a statistical error due to random photon emission and absorption and a curve fit error. The curve fit error may be reduced to any desired value, depending upon how sophisticated a system of computation is employed. Let the curve fit error be denoted by ϵ. Then the over-all system error is given by:

$$\frac{\Delta m}{m} = \alpha\epsilon + \frac{(1-\epsilon)}{\sqrt{n}} \frac{\log\left(1+\sqrt{\frac{k}{f_o \Delta t}}\right)}{\log k} \tag{9}$$

In equation (9) n is the number of detectors used, k is the maximum attenuation factor, f_o is the maximum detector output frequency, Δt the effective sampling time, and α is a constant whose value depends upon the nature of the curve fit error. If ϵ is a constant offset, then $\alpha = 1$. If ϵ is perfectly random, then $\alpha = \frac{1}{\sqrt{n}}$.

The statistical error $\epsilon\sigma$ given by

$$\epsilon\sigma = \frac{\log\left(1+\sqrt{\frac{k}{f_o \Delta t}}\right)}{\log k} \tag{10}$$

cannot be avoided, and must be reduced to tolerable values by proper selection of system parameters. Once the statistical error is known, the effect of curve fit error can be added on.

The objective of this analysis then is to find the source strength and detector characteristics required to yield

acceptable statistical error.

For this purpose, it is convenient to arrange equation (10) in the form

$$(k^{\epsilon\sigma}-1)^2 = \frac{k}{a} \tag{11}$$

where:

$$a = f_o \Delta t \tag{12}$$

The family of curves $(k^{\epsilon\sigma}-1)^2$ is plotted for various values of $\epsilon\sigma$ in Figure 2. These may be considered to be contours of constant $\epsilon\sigma$. k is determined from the relation:

$$k = e^{\mu\rho hM} \tag{13}$$

where μ is the mass absorption coefficient of the fluid to be gaged, ρ its density, and hM the maximum depth of fluid. Having found k, one then decides that the value of $\epsilon\sigma$ will be tolerated. Then, by equation (3) the ordinate of the point $k, (k^{\epsilon\sigma}-1)^2$ is the value of $\frac{k}{a}$ required to hold the statistical error to $\pm \epsilon\sigma$. Since k and k/a are known a can be found. Once a is known, suitable values of Δt and f_o can be determined.

2.1 Numerical Results for S IV B Hydrogen Tank

The procedure just described will now be applied to the S IV B hydrogen tank.

2.1.1 The source must be selected first. It is anticipated that the source strengths will be substantial because

of the large tank size involved. Hence, ease of handling, safety, and cost are prime factors affecting the final selection of the source. Discussion of these factors will be reserved for a subsequent section. In this section, the system parameters will be determined for several sources. Possible candidates are

(1) Kr^{85}

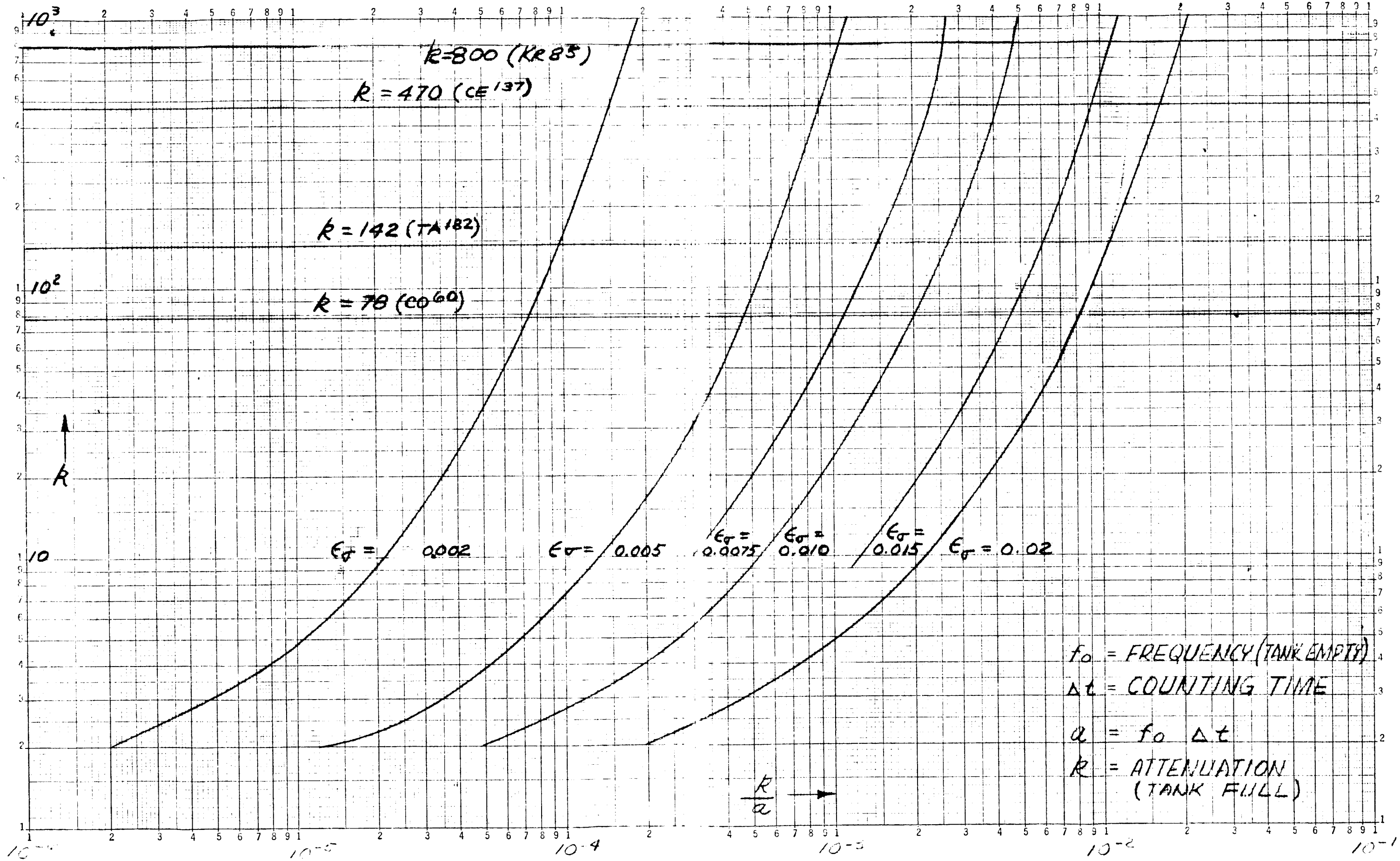
(2) Cs^{137}

(3) Ta^{182}

(4) Co^{60}

The maximum depth in the S IV B tank is 558 cm and the density of LH_2 is assumed to be 0.71 gm cm^{-3}. For the four sources listed, the mass absorption coefficients are respectively 0.17, 0.155, 0.125, 0.11 cm^2 gm^{-1}. The values of k for these sources are respectively 850, 470, 142, 78. These values are noted on Figure 2.

2.1.2 Maximum Frequency Required: The desired system accuracy is 0.25% of full load. The curves of Figure 3 are used to determine the accuracy at full load. It should be noted that the system accuracy improves as the fuel load is depleted. Since the systematic errors can be controlled by design, let 80% of the total allowable error be allotted to the statistical error. Twenty-five detectors will be used. Therefore, each detector may have a 1% error. The required values of k/a for the Kr^{85},



COUNTING STATISTICAL ACCURACY

FIGURE 3

Cs^{137}, Ta^{182}, and Co^{60} sources are respectively: $4.8x10^{-3}$, $4.1x10^{-3}$, $2.4x10^{-3}$, and $2x10^{-3}$. These in turn correspond to values of $1.77x10^{5}$, $1.15x10^{5}$, $5.9x10^{4}$, and $3.9x10^{4}$. It is desired to obtain at least 20 points on a run in which the tank is emptied at the maximum rate. At this rate, depletion occurs in 150 seconds. Therefore, an effective counting time of 7.5 seconds is tolerable. With this counting time, the f_o's required are 23.6 kc, 15.4 kc, 7.9 kc, and 5.25 kc.

2.1.3 Source Strength Required and External Dose Rate: The detector efficiencies for Kr^{85}, Cs^{137}, TA^{182}, and Co^{60} are respectively 0.11, 0.09, 0.07, and 0.05. For a 2-inch diameter detector then, the effective areas are 2.2 cm^2, 1.8 cm^2, 1.4 cm^2, and 1.2 cm^2. The f_o's computed in the previous section correspond to fluxes at the detector of 11,800, 8,600, 5,700, and 4,400 photons cm^{-2} sec^{-1}. These in turn correspond to dose rates at the detectors of 13, 10, 11, and 9 mr/hr, all of which are tolerable. In order to produce these detector fluxes, the required total source strengths are respectively: 195 curies, 920 mc, 600 mc, 230 mc per source.

3.0 SOURCE CONSIDERATIONS

The four sources discussed in the previous section are all suitable from a system performance viewpoint. From a safety viewpoint, however, Kr^{85} and Ta^{182} have distinct advantages. Krypton is a gas and will rapidly diffuse in the atmosphere in event of an accident. Tantalum is a dense, ductile metal with a melting temperature of 5400° F. Tantalum has no tendency to oxidize and its boiling point is above 7000°F. The tantalum would also be enclosed in about 9 pounds of tungsten. Since hydrogen is a reducing atmosphere for tungsten, the tungsten would not oxidize and hence would remain intact until its melting temperature of 6100°F is reached. There is thus very small chance that the source would even become unshielded. At worst, the tantalum might melt and re-solidify in several pieces. The tantalum would not, however, vaporize or oxidize. The tantalum pieces could be located by radiation detectors and recovered. The problem of recovering the tantalum would not be severe.

Krypton is satisfactory from a point of view of area contamination from an accident, but poses greater handling problems than dose tantalum. The greatest hazard in use of krypton is in the krypton handling system. Proper ventilation and pressure protection for the krypton distribution system and storage area must be provided. In addition, the distribution system will have to be shielded. All these problems have practical solutions, but

development of proper handling equipment for krypton seems beyond the scope of the present program.

3.1 Source Comparison

All four sources discussed are relatively cheap. Tantulum and krypton are superior from a safety viewpoint. Krypton has very low specific activity and requires sophisticated handling equipment. Furthermore, for system accuracy, a harder gamma is desirable.

Ta^{182} has suitable specific activity and meets safety requirements. The single disadvantage of Ta^{182} is its relatively short half life. The sources will have to be replaced periodically (about 120-day period), but this is not a serious problem, since the cost is low and the source preparation is a routine matter.

Cs^{137} can be used, but encapsulation will be more difficult since the enclosure must not only resist melting but must remain sealed. Ceramic binders which entrap Cs^{137} are available. Specific activities of 10 curies per gram can be achieved with 3M Company "microspheres". The presently available binders are good only to about 3000°F, but new developments are in progress, and warrant consideration. Cs^{137} is also somewhat easier to shield than Ta^{182}.

Co^{60} is comparable to Cs^{137}, but will require more weight for shielding. This is partially offset by the fact that the source strength requirement is lower for Co^{60}.

In view of the foregoing considerations, it seems that Ta^{182} is the source of choice for the prototype system. For future development Cs^{137} or krypton may prove superior.

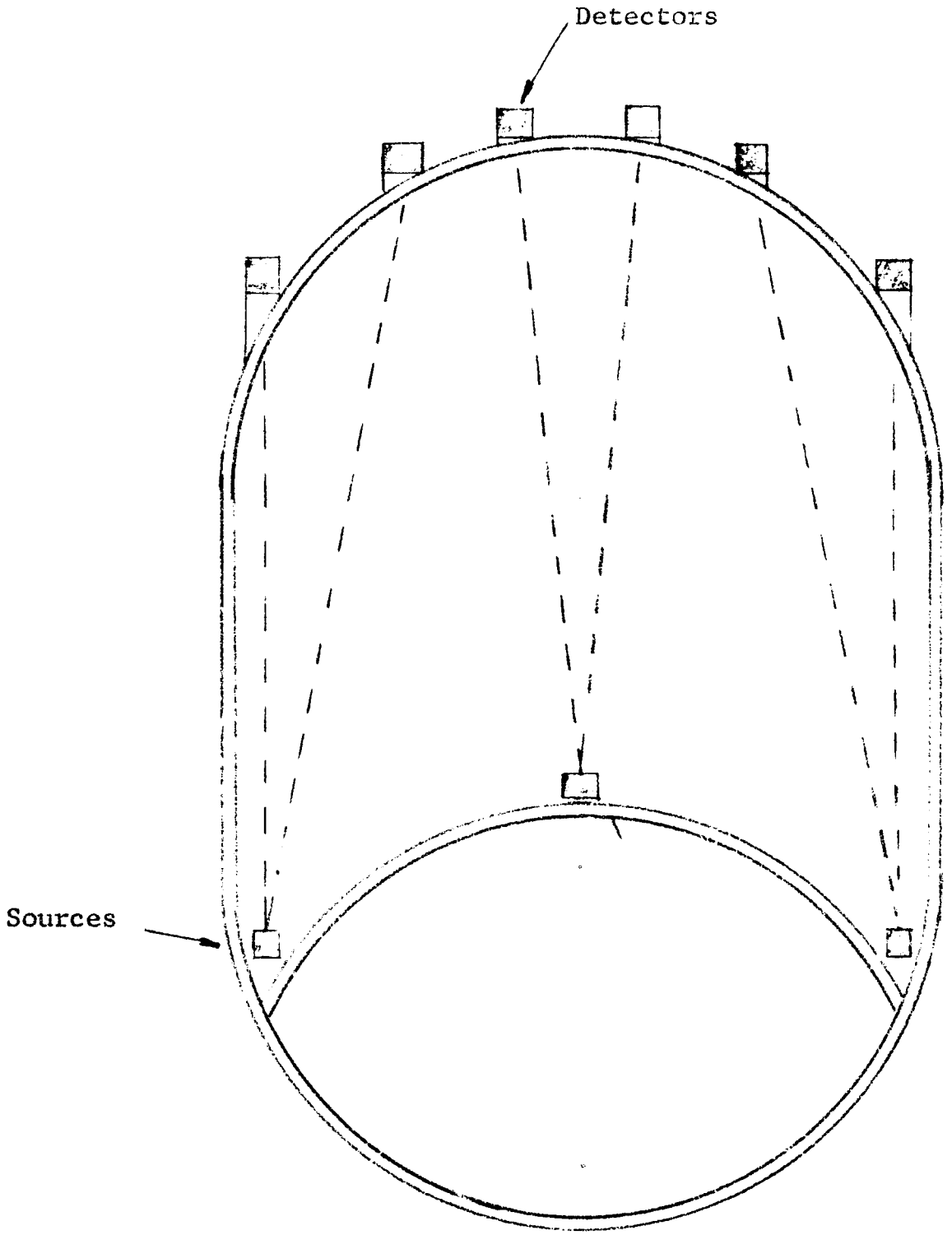
3.2 Source Installation

Analysis has shown that it is not necessary to have one source for each detector. Adequate coverage can be obtained with five sources located as shown in Figure 4. Thus, with Ta^{182} the total source strength will be 3.2 curies. A typical source is shown in Figure 5.

In Figure 6 a typical shield for the outboard sources is shown. These shields will be designed to limit the external dose rate to somewhere between 3.0 and 5.0 mr/hr one foot from the outside tank wall. The outboard shields will be made of tungsten. It is estimated that the outboard shield weight will be about 9.0 pounds each. The shield in the center of the bulkhead will also be tungsten; its weight will be approximately four pounds. The center bulkhead shield is shown in Figure 7. A detailed shield design is in progress. The weights given here are approximate.

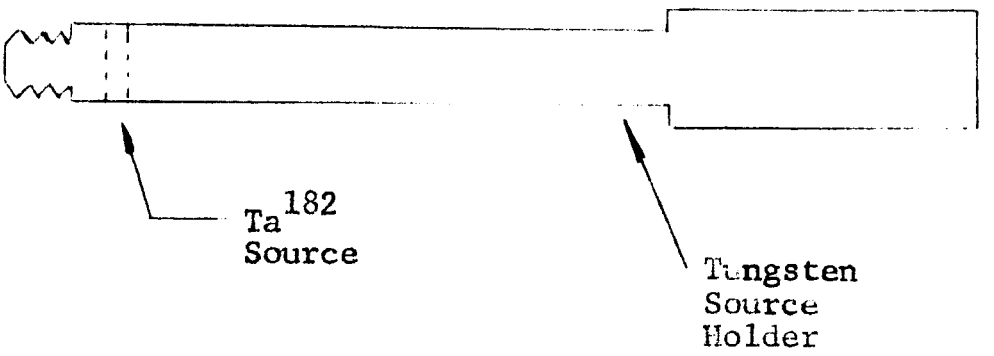
3.3 Source Handling Procedure

The sources will be transferred from their storage containers to the internal shields by the intermediate hemispherical shield, depicted in Figure 8. The source is removed from the storage container, but is still shielded by the tungsten hemisphere. The dose rate at the surface of the 8 cm radius



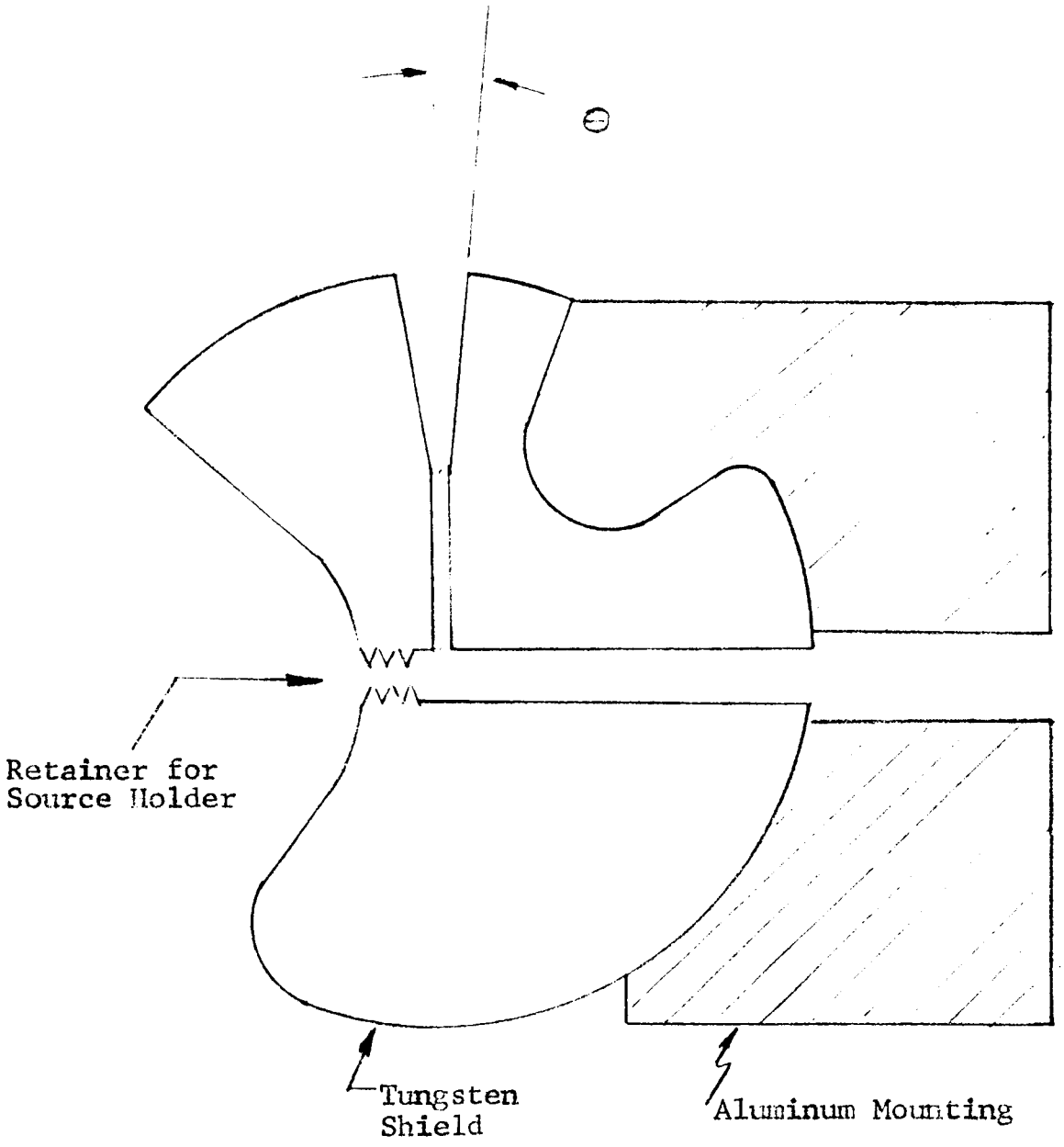
Source and Detector Arrangement

FIGURE 4



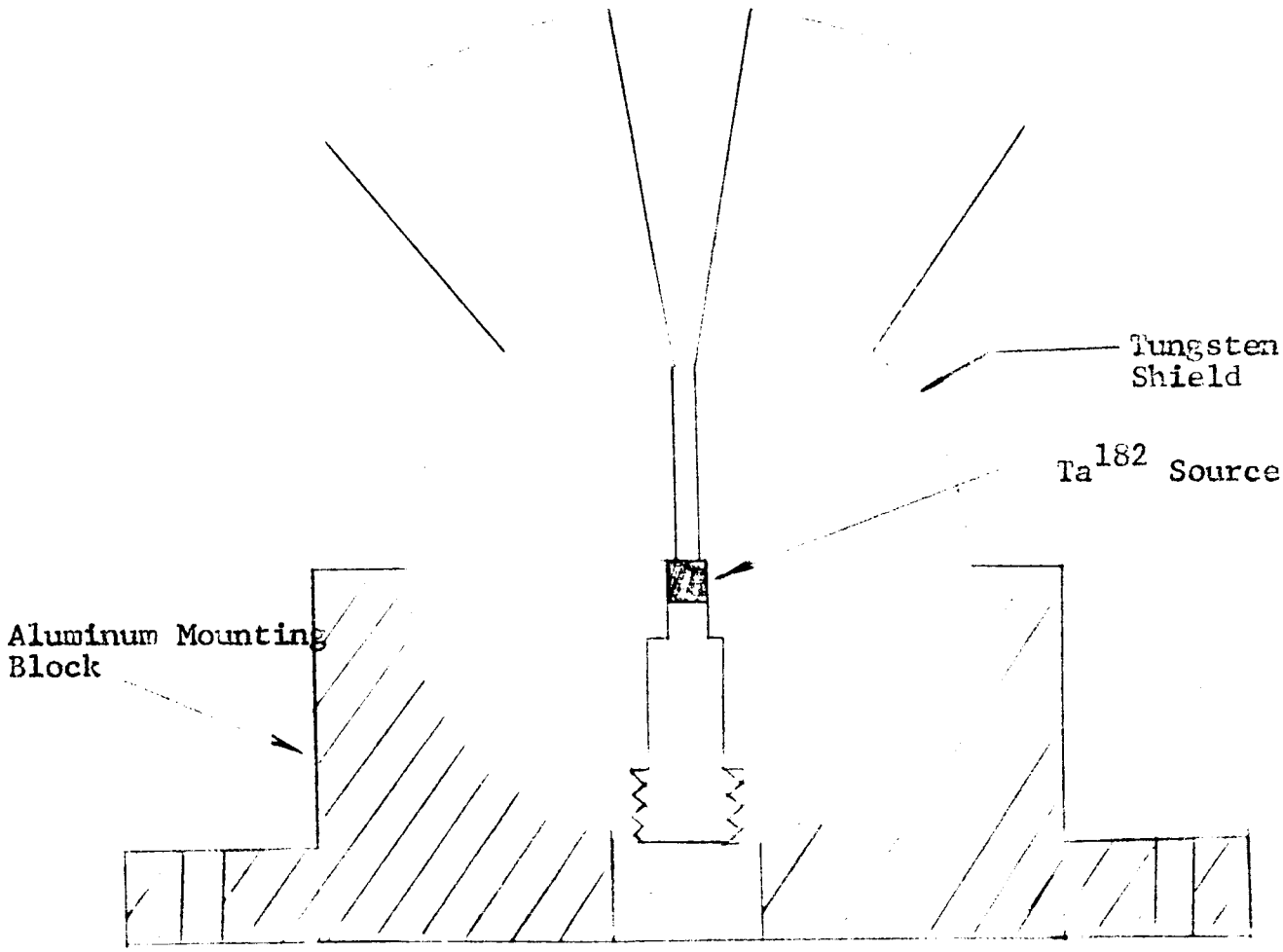
Typical Source for Outer Shields

FIGURE 5



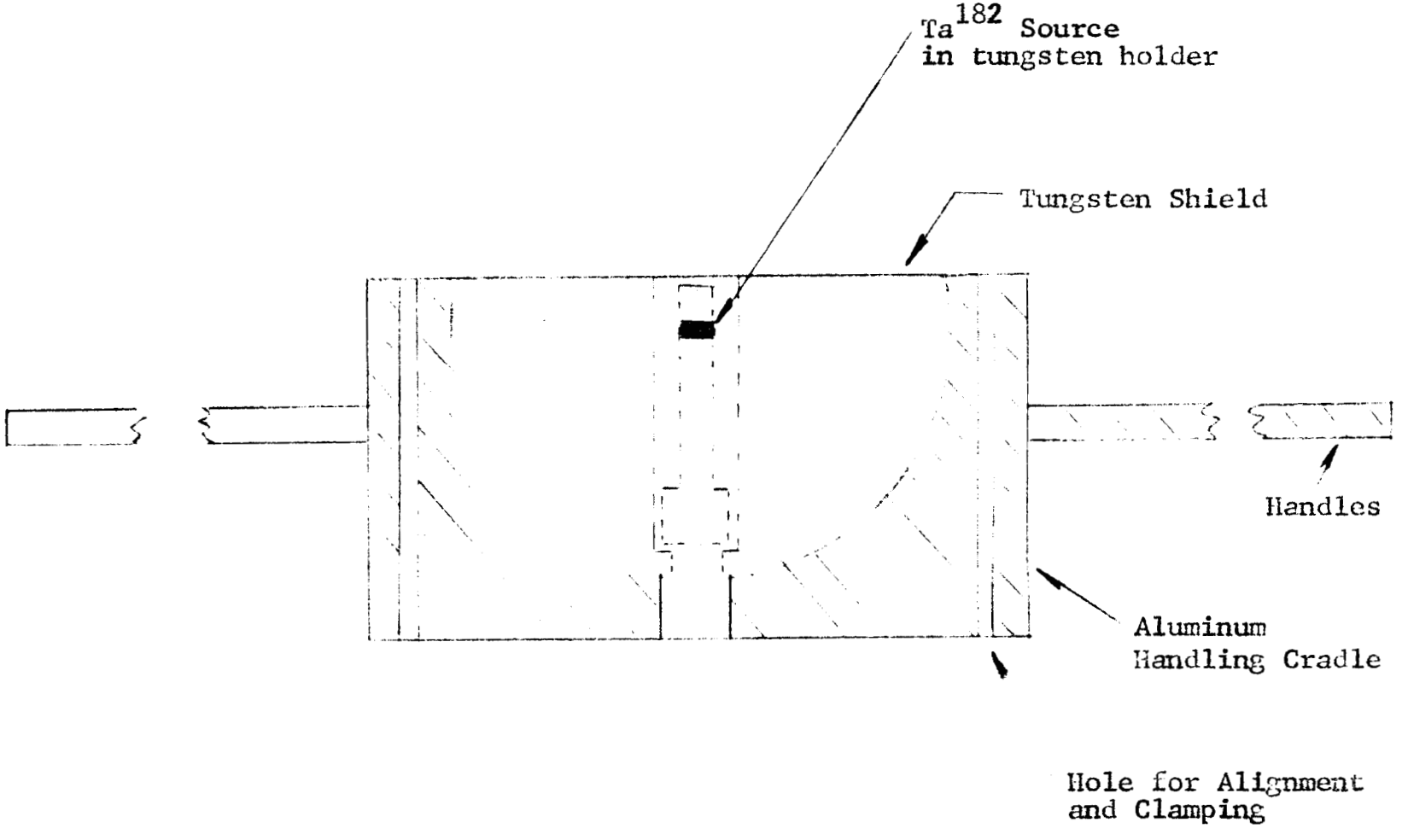
Outer Source Shield

FIGURE 6



Inner Source Shield

FIGURE 7



Source Handling Tool

FIGURE 8

EM-80208

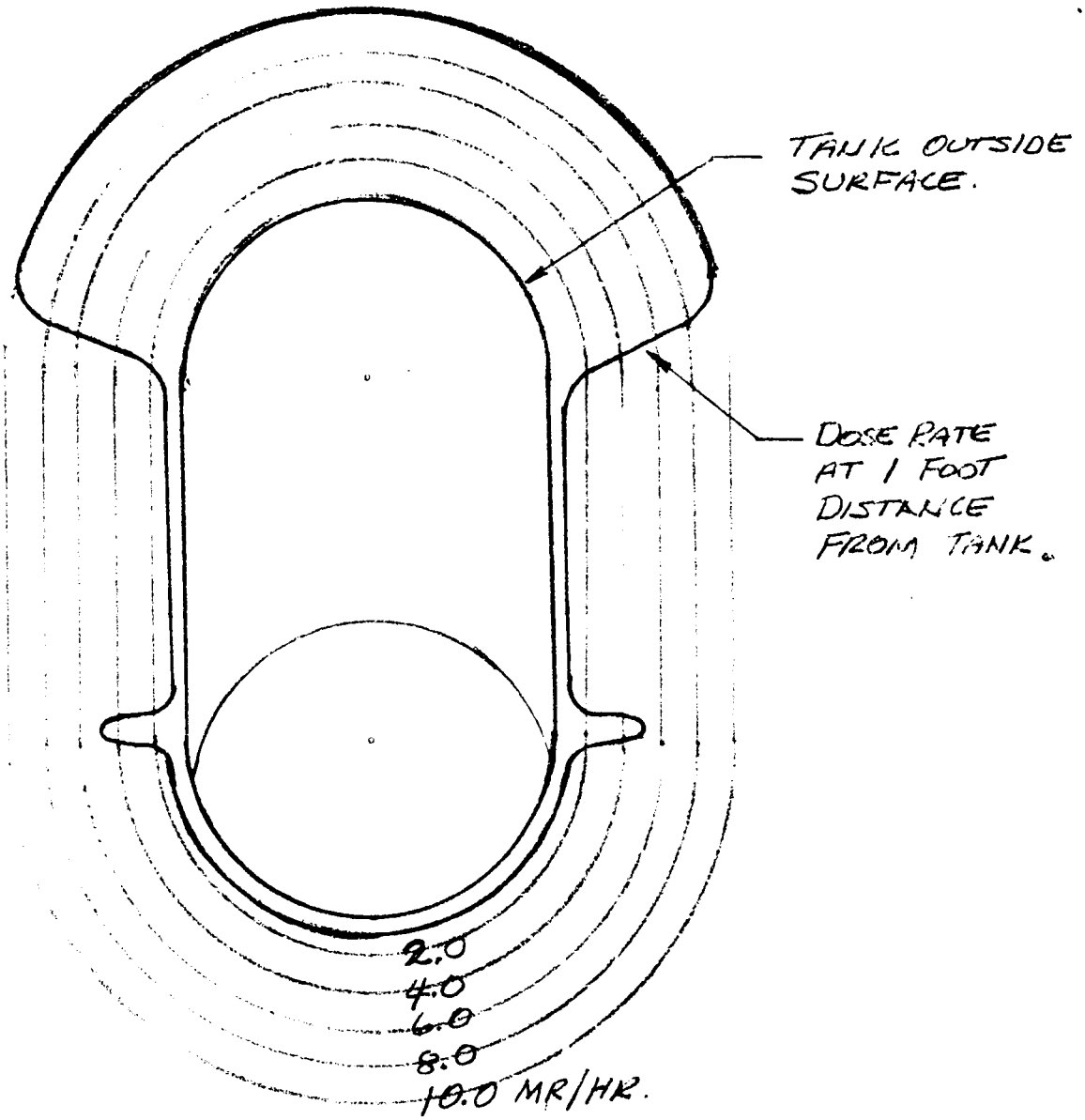
hemisphere is about 45 mr/hr. Thus, it is necessary to stay away from the front of the hemisphere and at least one foot from the rear surface. This is accomplished by handling the hemisphere by the handles provided only. Two men will be required to place the hemisphere in position on the tank wall. The source is then transferred from the hemisphere to the internal shield by means of the lead screw. Personnel engaged in source installation should be monitored, but they will never be exposed to more than 2.5 mr/hr if proper procedure is employed.

The removal and installation of these sources amounts to little more than installing a manhole cover on the tank.

The inboard source will be installed in a fully shielded condition. The shield will be removed (leaving only the collimation shield) when the tank is closed up. The outboard sources need not be installed until just prior to filling the tank. Thus, if it should be necessary to re-enter the tank, it is only necessary to lower the shield for the inboard source into position. With the shield in position, the dose rate inside will be negligible.

3.4 Radiation Level Around Tank

To summarize the external dose rate information, refer to Figure 9 which shows the dose rate levels at various points outside the tank when all sources are installed and the tank is empty.



Dose Rate One Foot Outside Tank Wall,

Tank Empty - All Sources Installed.

FIGURE 9

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