Feb. 4, 1969 G. R. SMITH 3,426,206

CONTROLLABLE IRRADIATION DEVICE

Filed Sept. 13 1965

FIG. 2

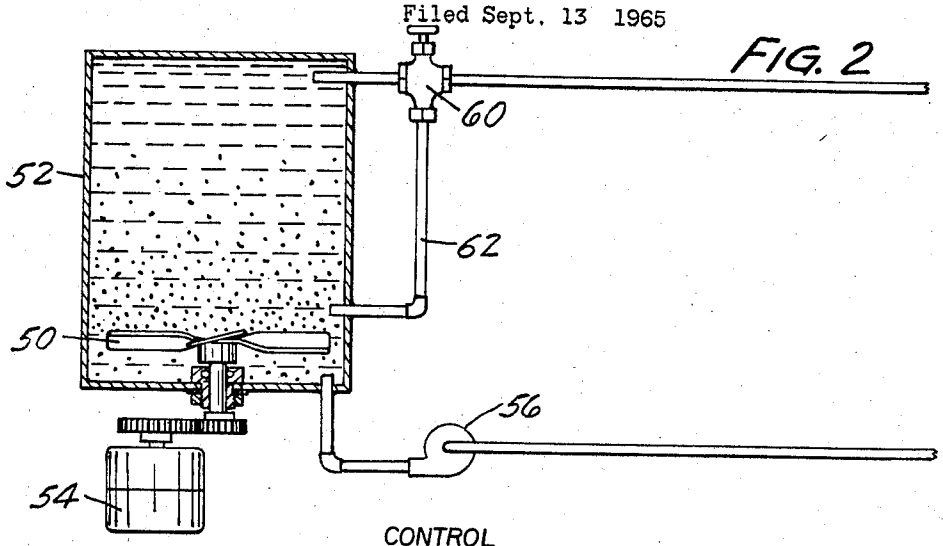
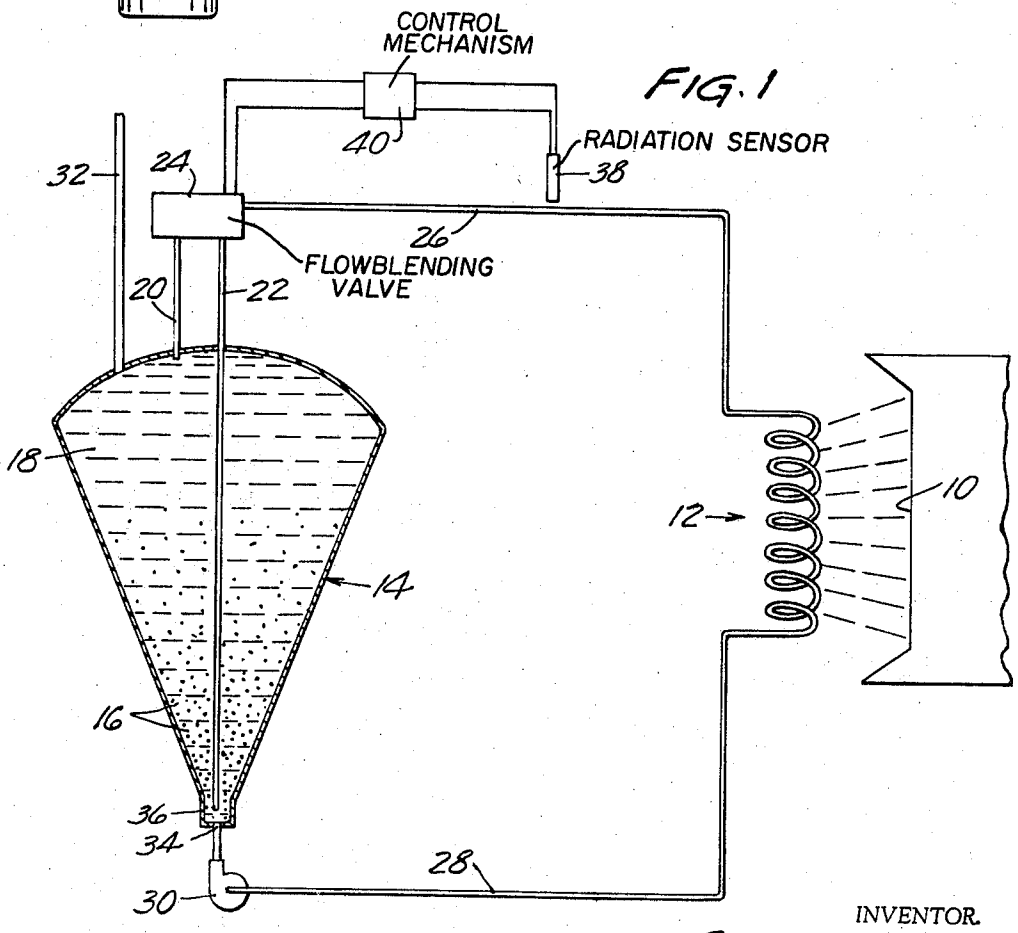


FIG. 1



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CONTROLLABLE IRRADIATION DEVICE

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ABSTRACT OF THE DISCLOSURE

Means for varying and controlling the intensity of radioactive emission directed toward a target area, in which a mixture of radioactive particles and a non-radioactive liquid is discriminately agitated to maintain the particles suspended in a first portion of the liquid and not in a second portion thereof. The particles and liquid drawn from the first portion and the clear liquid drawn from the second portion are selectively blended to achieve the desired intensity level and then directed to a tubing array in the vicinity of the target to be irradiated.

This invention relates to the handling of radioactive materials and especially to apparatus and method for controlling radioactive exposure of such materials.

Control of radioactive exposure as used herein refers to the capability of safely providing, within the capacity of the radioactive source being used, variable levels of radiation directed from the source to a desired subject or target area.

Such control of radioactive exposure is desirable or essential to such applications as nuclear testing programs for simulation of nuclear fall out, radioactive treatment of various medical ailments, and sterilization of food products (e.g. sterilization of fruit products for prolonging shelf life). Such control is also desirable for the practical use of sources having radioactive elements of relatively short half lives, which sources otherwise provide a rapidly declining radioactive exposure that in most applications is adequate for only a short period of time.

Prior attempts to control the exposure of radioactive sources have for example included movable shielding members designed to block various portions of the radiation being emitted from the source. As far as I am aware, however, such prior attempts have not provided a satisfactory means for effectively controlling radioactive exposure in a manner such as herein disclosed. Accordingly, I believe that a real need has been satisfied by my invention which is generally described as follows:

I entrain an immiscible radioactive source in a non-radioactive carrier liquid (hereafter referred to as a radioactive slurry), and circulate the slurry through a piping system. The system includes a tubing array that is positioned relative to a subject or target area for radioactively exposing the area to the circulating slurry. Said system further includes, at a point remote from said subject area, means for selectively varying the concentration of the radioactive source within the slurry and accordingly the amount of radiation directed to the subject area.

The invention will be more fully understood by reference to the following detailed description and drawings wherein:

FIGURE 1 is a schematic illustration of one form of the invention; and

FIGURE 2 is a schematic illustration of a second form of the invention.

Referring to FIGURE 1, a target area **10** is positioned with respect to an exposure tubing array **12** to receive radioactive emission from a radioactive source circulated through the tubing array. A piping system connects the

tubing array with a conical supply tank **14** containing a mixture of insoluble radioactive particles **16** suspended in a non-radioactive liquid **18**. The piping system includes dip tubes **20** and **22** which communicate the mixture in the supply tank with a flowblending valve **24**, a connecting tube **26** that is connected from the flowblending valve **24** to the tubing array **12** and a return tube **28** connected from the tubing array **12** back to the supply tank **14**. A centrifugal pump **30** positioned in the return tube, draws the liquid **18** and particles **16** from the tank **14** through dip tubes **20** and **22**, and circulates a mixture thereof (i.e. the radioactive slurry) through connecting tube **26** to the tubing array **12** and back to the tank through return tube **28**.

The particles **16** are more dense than the liquid **18** and are entrained in the flowing carrier liquid to provide circulation thereof through the system. Such entrainment is accomplished by maintaining the circulation of the liquid with a required minimum flow velocity (determined at the largest horizontal cross-section of the system) that is based on the particle size and its relative density with the liquid. Such velocity is specifically established for each individual system and can be calculated, determined experimentally or obtained from any of a number of well-known references, e.g. see Fluidization and Fluid Particle Systems, by F. A. Zenz and D. F. Othmer, p. 326 (Reichold Publishing Co., New York, 1960) and Aqueous Transport of Settling Slurries (May 1961) by G. A. Hughmark, Industrial and Engineering Chemistry, vol. 33, No. 5, p. 389.

The centrifugal pump **30** thus circulates the slurry at a volume rate of flow to provide a flow velocity at the largest horizontal cross-sectional area of the piping system that at least exceeds the required minimum velocity, i.e. the volume flow rate of the pump ($ft.^3/sec.$) will at least equal the said minimum velocity (ft./sec.) multiplied by the mentioned largest horizontal cross-sectional area ($ft.^2$).

The liquid within the tank is caused to flow by reason of the circulation of the slurry which enters through inlet **36** and is directed upwardly in the tank to be withdrawn by the dip tubes **20** and **22**. Due to the conical design of the tank wherein the cross-section of the tank increases as the liquid rises therewithin and because the volume rate of flow provided by the pump **30** is a relatively constant quantity, necessarily the flow velocity of the liquid within the tank decreases at a rate in accordance with said increasing cross-section. The conical tank **14** is designed for cooperation with the said constant volume rate of flow to provide a flow velocity of the liquid in a lower portion of the tank that is greater than the settling velocity of the particles for maintaining the particles in suspension, and an upper portion of the tank wherein the flow velocity is reduced below the settling velocity and the liquid therein is clear of the particles.

Thus, the actual volume rate of flow from the pump, e.g. in $ft.^3/sec.$ (which may be substantially greater than the above mentioned required minimum volume flow rate) is divided by the rate at which the particles settle in the carrier liquid, e.g. in ft./sec. (referred to as the sedimentation velocity which is calculated on the basis of Stoke's Law, e.g. see Chemical Engineer's Handbook by J. H. Perry) to establish a critical cross-section area, e.g. in $ft.^2$ wherein the upwardly directed flow rate from the inlet will be slowed down to the sedimentation velocity. The conical tank is designed to have this critical cross-sectional area at some intermediate point, below which the cross-section of the tank is at all points less than the critical cross-section, and above which the cross-section of the tank is at all points greater than the critical cross-section. Accordingly, the flow velocity of the liquid in the lower portion is sufficient for suspension of the par-

ticles whereas in the upper portion the flow velocity of the liquid is below the sedimentation velocity so that the particles will not be suspended. The particles within the slurry of the return flow will not rise in the tank above the point of critical cross-section and therefore said upper portion contains only the non-radioactive clear carrier liquid whereas the lower portion is heavily concentrated with the radioactive particles. (In practice the tank is provided with a substantial portion above said calculated intermediate point to hedge against a variation of the critical cross-section which may for example be caused by unexpected turbulence of a decrease in calculated particle size due to the wear of the particles as they flow about the system.)

Dip tube **20** is connected to an outlet at the top of the tank and communicates only with the clear liquid in the upper portion of the tank. Dip tube **22** extends through the top of the tank to a point near the return tube inlet and communicates with the concentrated mixture of radioactive particles and liquid in the lower portion of the tank.

A radiation sensor **38** (e.g. a Geiger counter) is positioned with respect to connecting tube **26** to detect the amount of radiation in the piping system and thus the amount of radiation directed at the target area from the tubing array. The sensor is interconnected with the control mechanism **40** of the flow blending valve **24**. Such control mechanism is well known to the art and incorporates a means for coordinating the setting of the flow blending valve with the reading of the sensor to maintain a proper balance of flow from the dip tubes for establishing within the piping system a desired radioactivity level. Higher and lower radioactivity levels are acquired by varying the mixture between the dip tubes so as to decrease or increase the amount of radioactive materials being carried by the slurry through the piping system.

The mixture of liquid and particles drawn out of the tank through both of the dip tubes, equals the incoming flow from return tube **28**. As the flow blending valve **24** is regulated to drawn more of the mixture through dip tube **22** and less liquid through dip tube **20**, the volume rate of flow of slurry within the tank after passing the mouth of dip tube **22** is reduced. Therefore the critical cross-section at which the particles settle from the slurry within the tank is also reduced and the mentioned intermediate point therein is correspondingly lowered. By setting the flow blending valve **24** to draw only through tube **22**, there is no flow within the tank above the mouth of tube **22**. All of the particles in the tank then settle to the mouth of tube **20** and are drawn into the piping system. Thus, essentially all of the particles are available for circulation in the system to enable a maximum utility. If it is desired to remove all radiation from the target area, e.g. to permit maintenance etc., the flow blending valve is adjusted to draw only through tube **20**. Only clear liquid is thus pumped into the system and all the particles are returned to the tank.

It will be noted from FIGURE 1 of the drawings, that dip tubes **20** and **22** are vertically positioned with respect to the supply tank. I have found that the tubes in this position are less likely to clog and easier to free when becoming clogged. Furthermore, the response to changes called for by the flow blending valve is faster and the overall performance achieved is more satisfactory.

It is also considered objectionable for gas (e.g. air pockets) to be circulated through the system and it is thus desirable for the tank **14** to be filled with the liquid **18** to its capacity. A standpipe **32** is connected to the tank and is filled with the carrier liquid **18** to a level above the tank to insure that the tank maintains that capacity. The standpipe furthermore functions to "bleed-off" any gases that are formed, e.g. because of the radioactive effect on the carrier liquid and also serves to indicate leakage in the system.

My invention will now be more specifically described with the aid of the following examples set forth to illustrate my invention and not to limit it.

Facility for simulation of nuclear fallout

A facility was desired in which an experimental volume could be uniformly irradiated with approximately 1.8 kilocuries of gamma radiation from cobalt 60. A radiation study relative to the geometry of the exposure tubing array showed that the necessary uniformity of radiation and the experimental volume could be obtained if the 1.8 kilocuries of cobalt 60 were distributed in three rings of 20, 40, and 60 feet diameters located in the respective elevations of 0, 6, and 12 feet. An engineering study indicated that 377 feet of tubing were required for the exposure tubing, and that an additional 105 feet of connecting and return tubing were required to circulate the slurry between the tubing array and supply tank. The connecting and return tubing required an additional .5 kilocurie of cobalt 60, and therefore the total system required 2.3 kilocuries.

The radiating material used in this facility consisted of cobalt 60 loaded micro-spherical material having a minimum diameter of 30 microns and a specific gravity of 3 grams per cubic centimeter. (Commercially available from Minnesota Mining and Manufacturing Company.) An effective specific activity of the cobalt 60 loaded microspheres was essentially .3 curie per gram of micro-spheres. Therefore 7,660 grams of cobalt 60 loaded micro-spheres were required for the system.

The preferred level of micro-sphere concentration was 5 percent by volume or less. Therefore, the length of the tubing required and the concentration of the microspheres in the slurry indicated the volume of the system necessary. From this length and volume the diameter of the tubing for the flow lines was calculated at .85 inch or the next nominal tubing size of 1 inch I.D.

Safety design considerations of the facility indicated that it was necessary to clear the experimental area of all radiation in 3 minutes. Assuming that the micro-spherical particles travel at no less than 80 percent of the velocity of the transport fluid, a velocity of 3.35 feet per second was found necessary, and a centrifugal slurry pump capacity of 8.25 gallons per minute was indicated. The minimum velocity necessary to maintain the particles in suspension for horizontal transport was found to be 2.0 feet per second. Even considering a 25 percent safety factor, the 3.35 feet per second velocity established for evacuation considerations was adequate.

The diameter of the flow lines in the system was determined as 1 inch I.D. and the required velocity was established at 3.35 feet per second, and thus the volume flow rate of the return tube could be calculated. According to calculations based on Stoke's Law, micro-spherical material of 30 microns diameter settling in water at 70° F. would settle at the rate of 4×10^{-3} feet per second. Accordingly, the critical cross-section of the tank was determined, i.e.

$$\text{critical cross-section}=\frac{\text{volume flow rate}}{\text{sedimentation velocity}}$$

The diameter of this critical cross-section was then calculated (critical cross section$=\pi d^2/4$) as being 28.5 inches. Previous experiment indicated that preferably the walls of the tank should be no greater than 45° angle with one another. The conical tank was constructed with a maximum cross-section that was double the critical cross-section which provided a maximum diameter of 40.5 inches and a height of 55 inches. The increase over the calculated critical cross-section provided a substantial upper portion of clear liquid as a safety factor for reasonable variation in the actual critical cross-section.

The system constructed according to this example successfully controlled the concentration of a radioactive source supplied to the tubing array.

A modification of the invention is illustrated in FIGURE 2 of the drawings. An agitator **50** is mounted on a shaft pivotally connected to the bottom of tank **52** which contains the mixture of non-radioactive liquid and insoluble radioactive particles. A motor **54** is engaged with the

shaft and operates to rotate the agitator. The agitator induces sufficient activation of the mixture to cause suspension of the particles within the liquid in the lower portion of the tank while allowing the upper portion to remain sufficiently calm for the particles to settle.

A centrifugal slurry pump **56** circulates the slurry through the system and in accordance with the setting of flow-blending valve **58** draws clear liquid through tube **60** and a concentrated slurry through tube **62**. The selected mixture or slurry is circulated through the system and to the tubing array in the same manner as described for FIGURE 1.

Numerous other variations are possible, for example, by using a liquid that is heavier than the particles the apparatus may be designed to induce sufficient activation in the upper portion of the tank for suspension of the particles therein while the lower portion remains sufficiently calm so that particles will rise from the lower portion into the upper portion to maintain the lower portion a clear liquid. This and other variations are encompassed within the scope of the following claims.

What is claimed is:

1. An apparatus for varying and controlling the intensity of radioactive emission directed to an exposure area comprising: a tank for containing immiscible radioactive particles and a non-radioactive carrier liquid wherein the liquid and particles have different densities; means to discriminately activate a first portion of the liquid sufficient for suspension of the particles in said first portion and for permitting a second portion to remain relatively inactive and clear of the particles, and means including flow blending means to selectively draw from the mixture of the first portion and from the clear liquid of the second portion to control the relative concentration of said radioactive particles in the liquid reaching said exposure area.

2. An apparatus for varying and controlling the intensity of radioactive emission directed to an exposure area comprising a conical tank having an inlet in the apex at the bottom of the tank, a mixture contained within the tank comprised of radioactive non-soluble particles suspended in a relatively less dense non-radioactive liquid; a piping system including a pair of tubular dip tubes that extend into the tank for communication with said mixture, a flowblending valve interconnecting the outer ends of the dip tubes, a connecting tube connecting the flow blending valve with a tubing array, and a return tube connecting the tubing array with the inlet at the apex of the tank; circulating means within the piping system for circulating the mixture from the conical tank to the tubing array through the dip tubes, flow-blending valve and connecting tube, and back to the tank through the return tube and said inlet at the tank's apex, at a rate sufficient to maintain the radioactive particles suspended in the carrier liquid at all points within the system, said conical tank having an intermediate cross-section where the velocity of the upward flow of mixture within the tank induced by said circulation equals the sedimentation velocity of the particles within the liquid to define an upper portion within the tank wherein the particles will not be suspended in the liquid, one of said dip tubes communicating with said upper portion above the intermediate cross-section and the other dip tube communicating with a lower portion wherein the particles are suspended.

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U.S. Cl. X.R.

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