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USE OF A CO_2 PELLET NON-DESTRUCTIVE CLEANING SYSTEM TO DECONTAMINATE RADIOLOGICAL WASTE AND EQUIPMENT IN SHIELDED HOT CELLS AT THE BETTIS ATOMIC POWER LABORATORY

T. R. Bench

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BETTIS ATOMIC POWER LABORATORY WEST MIFFLIN, PENNSYLVANIA 15122-0079

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Abstract

This paper details how the Bettis Atomic Power Laboratory modified and utilized a commercially available, solid carbon dioxide (CO_2) pellet, non-destructive cleaning system to support the disposition and disposal of radioactive waste from shielded "hot" cells. Some waste materials and equipment accumulated in the shielded hot cells cannot be disposed directly because they are contaminated with transuranic materials (elements with atomic numbers greater than that of uranium) above waste disposal site regulatory limits. A commercially available CO_2 pellet non-destructive cleaning system was extensively modified for remote operation inside a shielded hot cell to remove the transuranic contaminants from the waste and equipment without generating any secondary waste in the process. The removed transuranic contaminants are simultaneously captured, consolidated, and retained for later disposal at a transuranic waste facility.

Introduction

Each shielded hot cell was designed primarily as a radiological shield to protect personnel from the high levels of radiation from the radioactive materials within the cells. Contamination is controlled through containments over the major openings into the cells and through the use of forced, continuous, filtered ventilation which provides a negative pressure within the cells relative to the surrounding environment.

Work performed on radioactive materials within the shielded hot cells resulted in high levels of radioactive contamination being deposited on the equipment and structures within the cells.

System Description

The CO_2 pellet non-destructive cleaning system operates like a sand blaster, but uses tiny frozen pellets made of carbon dioxide, commonly referred to as "dry-ice". The dry-ice pellets, approximately 1/8 inch in diameter by 1/4 inch long, are manually loaded into a hopper and accelerated through a nozzle by compressed air to strike the surface being cleaned. When the dry-ice pellets hit the surface, their kinetic energy causes them to shatter and fragment, penetrate to the base material, dislodge the contaminants from the base material, and sublime, leaving no secondary waste. The sublimed dry-ice pellets, now CO_2 gas, returns to the atmosphere through the filtered radiological ventilation portion of the system. The system also employs a spot vacuum recovery subsystem to collect the dislodged contaminants via a cyclone separator stage and deposit the residue into a disposal container. Since the temperature of dry-ice is approximately -100°F, implementation of spot vacuuming required the development and design of equipment capable of operating in a cryogenic environment without compromising the integrity of the effluent's radiological filtration system.

The system has the following characteristics:

- remotely operated by manipulators
- minimizes the likelihood of spreading contamination in the shielded hot cells by incorporating localized vacuum flow to recover the dislodged particles
- captures the dislodged waste particles and places the particles into a container ready for processing and disposal
- eliminates the generation of secondary waste during the cleaning operations
- protects the operators from receiving unnecessary exposure

Using this system, contact radiation levels on waste and contaminated equipment have been reduced 100 to 200 fold.

Using dry-ice pellets to blast the contaminants off the waste and equipment reduces contamination levels to below the disposal site's transuranic limits, permitting disposal that would otherwise be prohibited. No secondary waste is generated. Only the cleaning residue collected in the cyclone separator remains as transuranic waste. This volume is much less than 1% of the original waste and equipment volume. In addition to removing the transuranic materials from the waste and equipment, the system also decontaminates scrap and equipment contaminated with highly radioactive particles. In this application, the radiation levels on the decontaminated scrap and equipment are reduced to a point where disposal as Low Specific Activity waste in unshielded containers is possible. A cost savings of approximately 94% per cubic foot of waste and a 90% reduction in man-rem exposure results.

Discussion

Eight components and assemblies required development to provide the shielded hot cells with a CO_2 non-destructive cleaning system:

1) Remotely operated CO_2 pellet blasting gun with vacuum recovery
2) Remotely operated CO_2 pellet blasting hood with vacuum recovery
3) Remotely operated in-cell filter train for vacuum recovery
4) Shielded hot cell plug
5) Solid CO_2 pellet storage hopper and gun controller
6) Air delivery system
7) Solid CO_2 pellet manufacturing, storage and transfer system
8) Vacuum supply system.

Remotely Operated CO_2 Pellet Blasting Gun With Vacuum Recovery

This assembly is designed to be handled and operated remotely by either master slave or motor driven manipulators and consists of three components: 1) a remotely activated blasting gun which combines the CO_2 pellets with the blasting air stream, 2) a vacuum recovery nozzle with a superdry air annulus to recover the effluent from the cleaning operation, and 3) an interface between the gun and nozzle which serves to protect the gun barrel from damage and provide a means for the manipulators to grasp the assembly. See Figure 1.

The operational mode for this assembly can be described as:

- the blasting zone is flooded with superdry air from the annulus around the vacuum recovery nozzle
- CO_2 pellets are shot down through the center of the nozzle
- the pellets hit the surface being cleaned and dislodge the contaminants
- the pellets sublime to the gas state
- the contaminants trapped within the nozzle are vacuumed through a tube attached to the side of the nozzle.

The annulus around the vacuum recovery nozzle allows superdry air to flood the blasting zone prior to, during, and after the blasting operations. Flooding the blasting zone with superdry air keeps moisture laden ambient air, within the shielded hot cell, from intermixing with the blasting effluent and being vacuumed into the in-cell filter train. If moist ambient air is vacuumed into the in-cell filter train with the cold CO_2 gas, the moisture will condense out of the effluent stream, as the mixture goes through its dew point temperature, and foul the in-cell filter train.

Remotely Operated CO_2 Pellet Blasting Hood With Vacuum Recovery

This assembly is designed to be stationary within the shielded hot cell and provides a container for cleaning small, irregularly shaped items under vacuum. Items to be cleaned are placed into the hood by master slave manipulators. The CO_2 gun is aimed into the hood and blasts the exposed surfaces of the item. The CO_2 pellets sublime upon impact and the dislodged waste particles are vacuumed to the in-cell filter train through a tube attached to the side of the hood. When the exposed surfaces are clean, the gun is turned off and the item is rotated by the manipulators to expose another surface. The cleaning process is repeated until all surfaces are cleaned. See Figure 2.

The commercially available blasting hood was modified for remote operations. A raised screen platform within the hood keeps the components off the floor and allows the contaminants blasted from the item to be vacuumed away. The vacuum hood contains an air diffusor which continuously floods the blasting zone with superdry air to prevent the moisture laden ambient air in the shielded hot cell from intermixing with the blasting effluent and being drawn into the in-cell filter train.

Remotely Operated In-cell Filter Train for Vacuum Recovery

A three-stage filter train was designed to filter out the particulates from the vacuumed air stream transporting the contaminants liberated during the cleaning operations. See Figure 3.

The first stage of the filter train is a cyclone separator designed to remove particulates from the effluent stream and deposit the waste particles into a waste container. The waste container is designed for direct placement into the shipping container of a shielded transportation cask. After the waste container is placed into the shipping container, the shipping container is sealed and retained in the shielded hot cell until it is transferred to a disposal site. This reduces the amount of waste handling prior to disposal. Measurements of the particles captured and retained in the cyclone separator's waste container show the separator is removing particles seven microns in size and larger from the effluent.

The second stage of the filter train is an off-the-shelf filter rated for particulates down to four microns in size. The filter housing is designed for the remote replacement of the filter by master slave manipulators.

The third and final stage of the filter train is a high efficiency particulate air (HEPA) filter rated for 99.97% at 0.3 microns. Prior to installation into a shielded hot cell and committal to a radiological environment, the HEPA filter is installed and DOP tested within a sacrificial filter housing. The HEPA filter and sacrificial filter housing are installed and attached to the in-cell filter train's main body by remotely operated screws and keyways. Once installed, the HEPA filter provides the last stage of filtration prior to the effluent exiting the cell to the vacuum source.

Cryogenic conditions exist which may have a detrimental effect on the integrity of the HEPA filter. The HEPA filter is rated for Arctic conditions to -64°F whereas the dry-ice pellets are at approximately -100°F. Extensive testing of the equipment under the worst possible accident conditions, where the entire 200 lb. complement of CO_2 pellets contained within the CO_2 pellet storage hopper and gun controller were vaporized and vacuumed into the filter train, indicates the temperature of the filter train approaches the Arctic conditions but does not drop below -64°F. To ensure the filter's temperature does not approach Arctic conditions, an operating parameter table for each setting of the pellet delivery rate from the CO_2 pellet storage hopper and gun controller was developed. The operating parameters were based on empirical testing and monitoring of the filter train temperatures during worst case scenarios and keeps the filter medium above 0°F.

Shielded Hot Cell Plug

The cell plug is hollow, non-stepping and constructed of carbon steel. Shielding was not required for this application because the placement of the cell plug in the shielded hot cell was at a point of low radiation. Three access through-tubes are provided for two air lines and one vacuum line. See Figure 4.

The in-cell CO_2 blasting gun requires two air lines, one for delivering the CO_2 pellets and the second to provide the driving air stream to propel the pellets and provide superdry air to the blasting zone. Two air lines are installed through the cell plug and incorporate a seal to prevent contaminants from migrating out of the cell through the annulus surrounding the lines.

The out-of-cell vacuum supply for the in-cell blasting gun and blasting hood is provided by a DOP-tested HEPA filtered vacuum cleaner located near the cell. This requires a vacuum line into the cell. The cell plug is equipped with a tube for the attachment of the vacuum line and a ball valve to isolate the vacuum line during periods of inactivity when the vacuum is not required.

Solid CO_2 Pellet Storage Hopper and Gun Controller

The pellet storage hopper and gun controller is a commercially available CO_2 portable cleaning station, modified for remote operations. The station, located outside but near the cell, is the staging point for the CO_2 pellets, and regulates the pellet delivery rate and blasting pressure. The hopper is manually loaded with CO_2 pellets generated elsewhere and contains an air lock system which reduces the possibility of contaminants entering the unit by migrating down the length of the pellet delivery and air supply lines. The pellet and air lines from the unit enter the cell through the cell plug where they combine with the remotely handled blasting gun. Special features unique to this cleaning station include:

- two hose delivery system; one for pellet delivery to the gun, one for blasting air
- operating range of 40 to 250 psig
- manually loading pellet hopper
- regulated blasting air pressure
- regulated pellet delivery air pressure
- regulated superdry air for flooding the blasting zone
- four pellet delivery rates: Economy, 2 lb/min; Standard, 3.5 lb/min; High, 5 lb/min; Maximum, 6 lb/min
- agitator in the pellet storage hopper to prevent ice bridging
- remotely handled and self-cleaning blasting gun
- remotely operated and programmable operating switch

The commercially available blasting gun was modified for remote operation. The gun body is designed to accommodate manipulation by either master slave or motor driven manipulators in the cell and be integral with a vacuum recovery shroud.

The operating switch for the gun is designed for operation away from the control panel of the pellet storage hopper and the in-cell gun. This allows the operator to activate the blasting sequence from the area of the shielded hot cell window where the cleaning operations are being observed. The switch is programmable and allows the operator to set the length of blasting time based on the pellet delivery rate to keep the blasting sequence and vacuumed effluent within the operating parameters of the system.

A second air supply line, complete with an isolation valve and air pressure regulator, has been installed on the unit to provide a continuous supply of superdry air to the blasting zones. This second air supply line prevents the moisture laden ambient air in the shielded hot cell from entering the vacuum recovery system during blasting operations.

Air Delivery System

The air delivery system is made up of commercially available components and provides clean, dry, oil-free air to the CO_2 pellet storage hopper and gun controller, and the blasting zones. Air filters, receivers, and driers, integral to the system, provide a dew point below -40°F. This low dew point prevents the CO_2 gun from freezing up with ice crystals during operation.

The air delivery system is composed of three main components:

1) Rotary screw, 60 hp, 247 ACFM, 125 psig, air cooled air compressor
2) 200 gallon vertical air receiver
3) Pressure swing, desiccant type, compressed air dryer set for a -40°F dew point.

The compressor, air receiver, and air drier are attached to two separate transportable pallets. This allows the equipment to be relocated to other shielded hot cells being decontaminated without major disassembly.

Solid CO_2 Pellet Manufacturing, Storage, and Transfer System

The commercially available CO_2 pellet manufacturing, storage, and transfer system is installed out-of-cell and consists of three main components:

1) 6-ton capacity liquid CO_2 storage tank
2) CO_2 pelletizer
3) 400 lb. capacity mobile CO_2 pellet storage bin.

The 6-ton capacity liquid CO_2 storage tank is located outside and adjacent to the building containing the CO_2 pelletizer. A supply line, with appropriate isolation and relief valves, was installed to supply liquid CO_2 to the CO_2 pelletizer.

Care must be taken to ensure the level of CO_2 gas in the vicinity of the pelletizer and the breathing zone of the workers, does not exceed allowable levels. The CO_2 pelletizer converts liquid CO_2 to dry-ice pellets. Pellets made in the pelletizer are transported to a portable pellet storage bin located adjacent to the liquid CO_2 storage tank through a pellet transfer hose. During the manufacturing of the pellets, excess CO_2 gas within the pelletizer is vented to the atmosphere, outside of the building, through two additional hoses. A 140 cfm blower was added to the pelletizer's cabinet to ventilate any CO_2 leakage in the cabinet to the outside of the building. In addition to the blower, a CO_2 detector was installed adjacent to the pelletizer to monitor CO_2 levels.

The 400 lb. capacity, mobile CO_2 pellet storage bin is basically an ice chest on wheels. In operation, the end of the pellet transfer hose from the pelletizer is placed into the open top of the bin and the pelletizer turned on. When the bin is full, the pelletizer is turned off, the pellet transfer hose removed, and the bin's lid secured with clamps. The loaded CO_2 pellet storage bin is then wheeled to the shielded hot cell where the pellets are manually scooped from the bin into the hopper of the portable cleaning station.

Vacuum Supply System

The vacuum for the blasting gun and hood is supplied by a commercially available DOP tested HEPA filtered vacuum cleaner located out-of-cell and connected to the in-cell portions of the cleaning system through the cell plug. The effluent from the vacuum cleaner is directed back into the cell through an air diffusor, and processed by the cell's ventilation system prior to being discharged to the environment.

The HEPA filtered vacuum cleaner selected for this application offers two stages of filtration, 1) a roughing filter with an efficiency of 95% at 1 micron, and 2) a DOP tested HEPA filter with an efficiency of 99.97% at 0.3 microns. The unit is capable of providing approximately 95 inches of water vacuum. However the normal operating range for this application is approximately 20 inches of water vacuum with a system flow rate of 250 SCFM.

Conclusion

The use of solid CO_2 pellets as a cleaning medium for radiologically contaminated waste and equipment is a viable and very efficient technique. The Bettis Atomic Power Laboratory has been very successful in developing this technique for use in its shielded hot cells. Radioactive waste that was previously non-disposable, because of transuranic contamination, is now being decontaminated to a condition that permits disposal. In addition to the transuranic contaminants, high radiation levels on non-transuranic waste are being reduced so that shielded disposal containers are not required. This reduces disposal volume and cost. The small volume of concentrated transuranic residue from the cleaning process is being automatically collected in disposable containers suitable for direct placement into shipping casks for future transfer to a transuranic disposal facility. Savings associated with this technique include a greater than 99% volume reduction in transuranic waste and a 90% reduction in man-rem exposure.

Figure 5 shows an overall schematic of the system.

FIGURE 1

BLASTING GUN WITH VACUUM RECOVERY

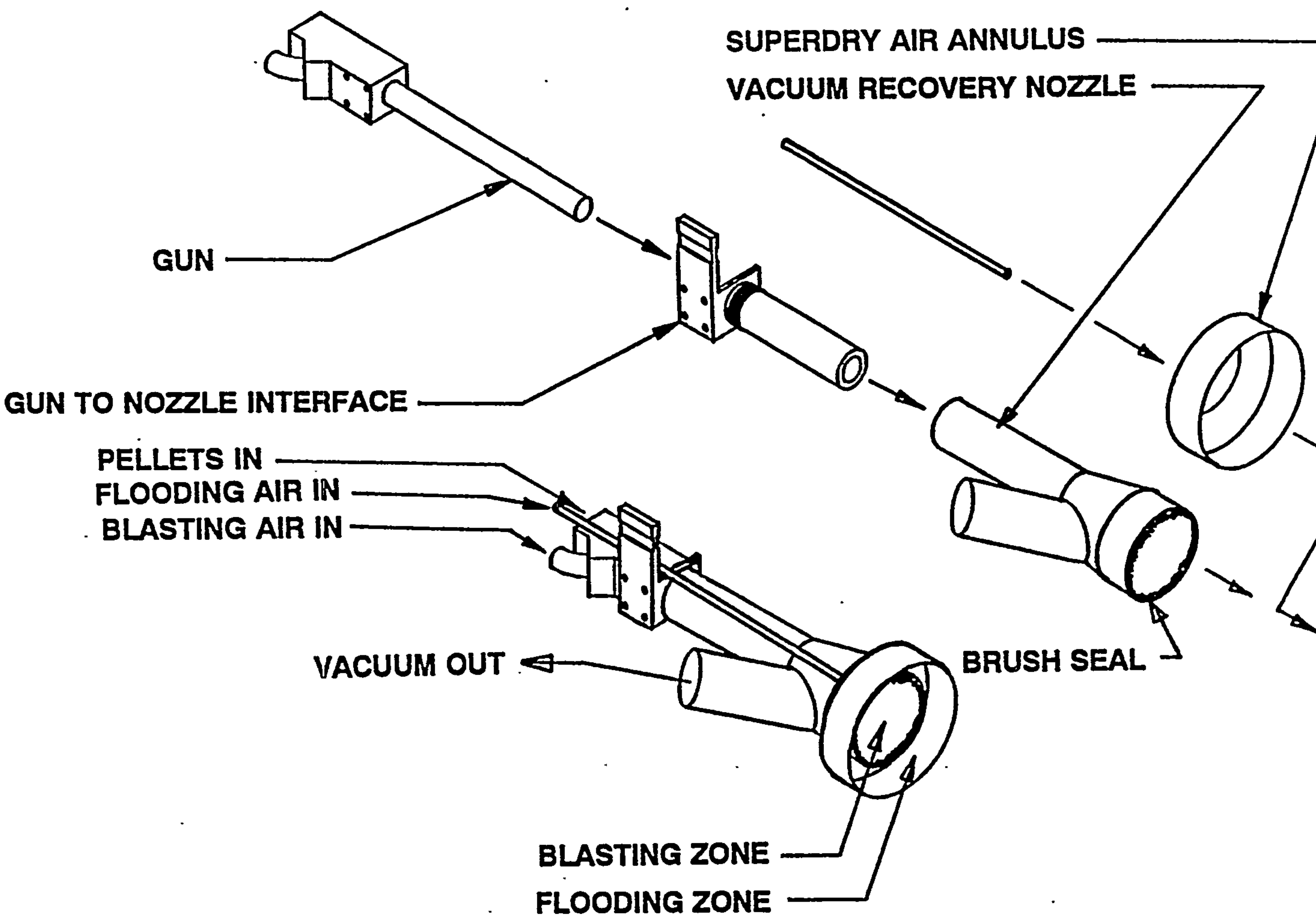


FIGURE 2

BLASTING HOOD WITH VACUUM RECOVERY

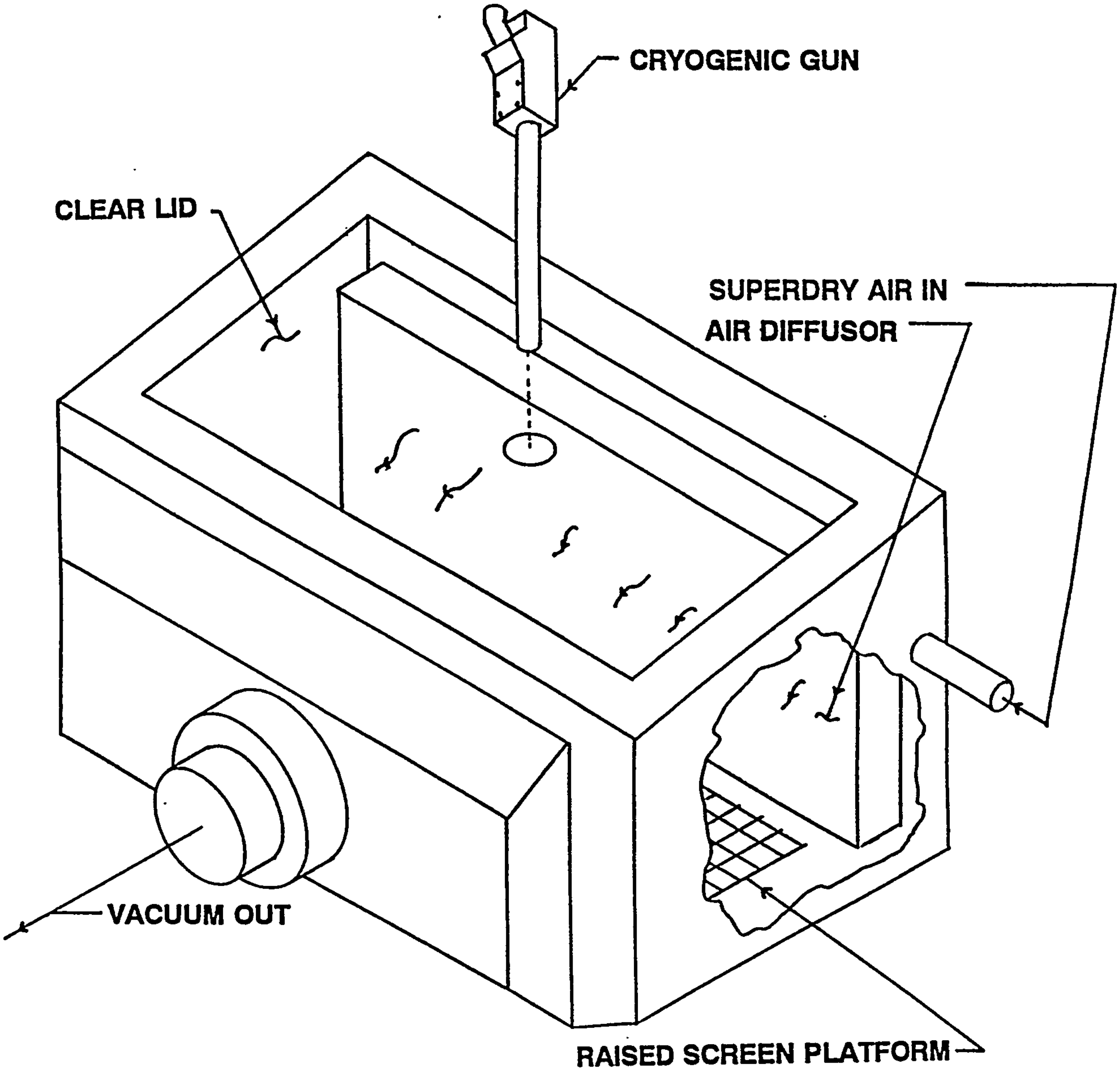


FIGURE 3

IN-CELL FILTER TRAIN FOR VACUUM RECOVERY

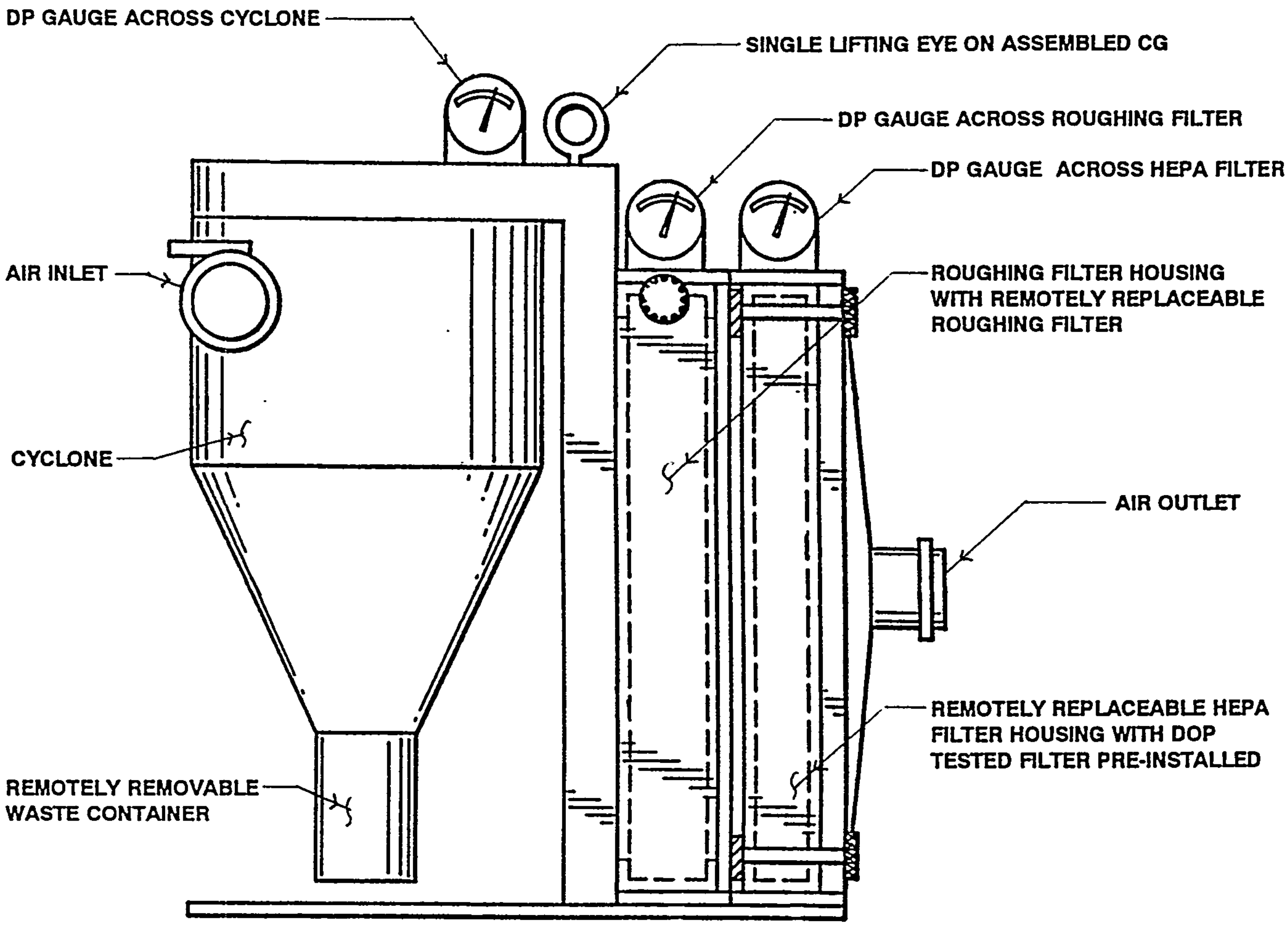


FIGURE 4

SHIELDED CELL PLUG

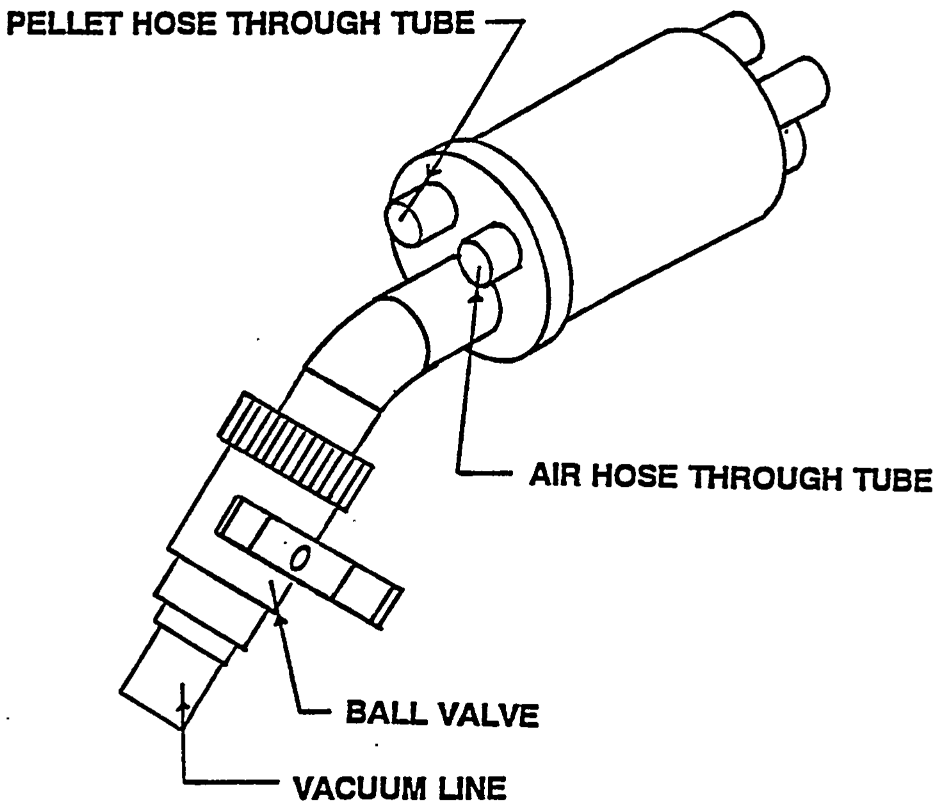
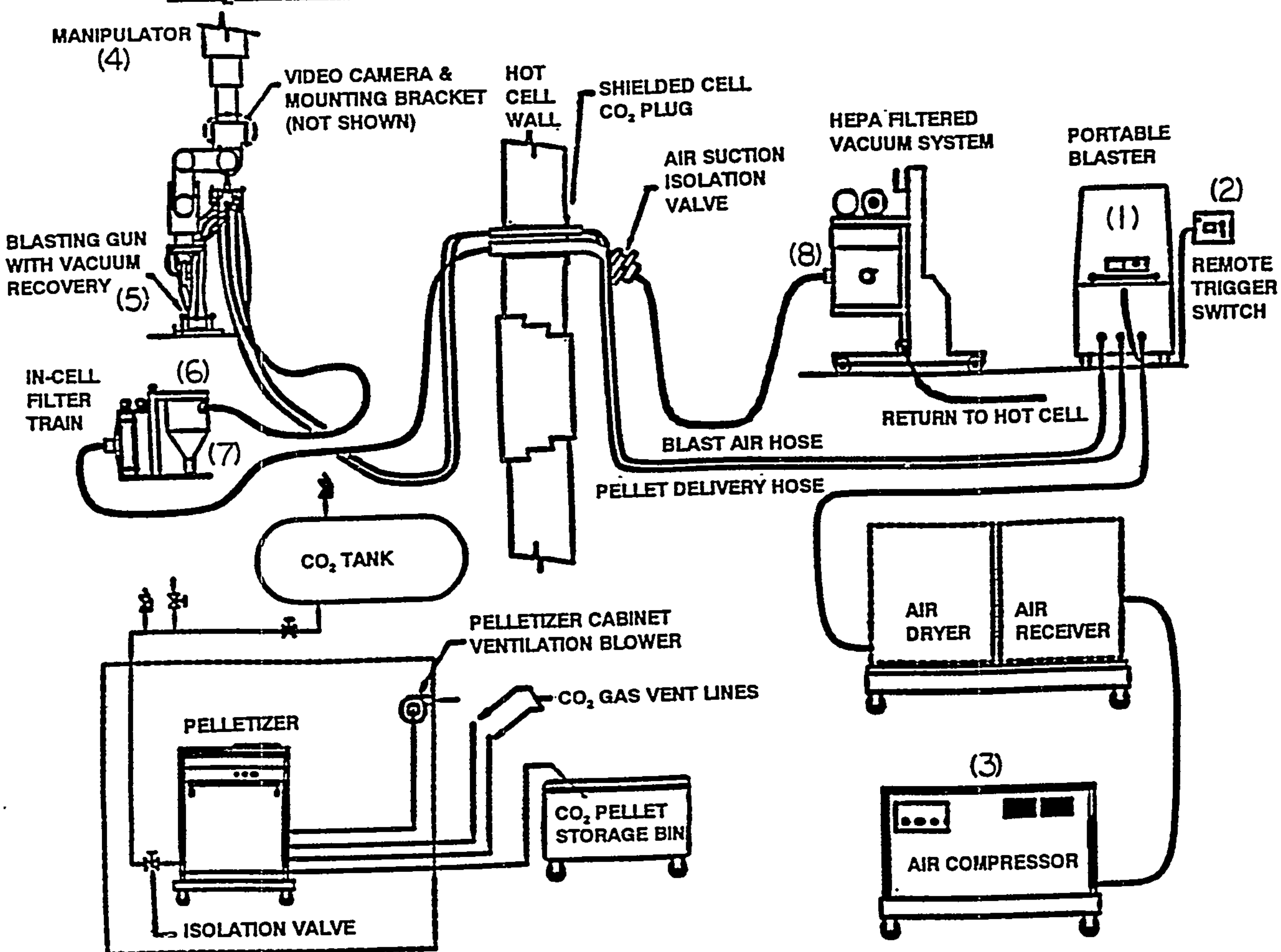


FIGURE 5

CO_2 PELLET NON-DESTRUCTIVE CLEANING SYSTEM



- Dry-ice pellets are manually loaded into the portable blaster (1).
- A remote trigger switch (2) is programmed for on/off blasting times.
- Air from the air compressor (3) drives the pellets to the gun held by the in-cell manipulator (4).
- The gun shoots the pellets either through the blasting gun with vacuum recovery (5) or into the blasting hood with vacuum recovery (not shown).
- The item is cleaned and the effluent with the dislodged particles is vacuumed into the in-cell filter train (6).
- The effluent particles are retained by the cyclone separator (7) for later disposal.
- The effluent gas continues out of the hot cell through the cell wall, through the vacuum supply system (8), and back into the hot cell through an air diffusor.