A STUDY OF EFFLUENT CONTROL TECHNOLOGIES EMPLOYED BY RADIOPHARMACEUTICAL USERS AND SUPPLIERS*

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INTRODUCTION

The medical use of radionuclides has resulted in the evolution of a large radiopharmaceutical industry. This industry is made up of suppliers that produce or package radionuclides and users primarily hospitals and physicians. The quantities of radiopharmaceuticals produced for in-vivo diagnostic and therapy procedures has been estimated to be growing at the rate of 16% per year,(1) based on 1978 sales figures. Nuclear medicine facilities are experiencing an average annual growth rate of 5% per year.

The principle radionuclides produced and used for nuclear medicine are $^{131}$I, $^{133}$Xe and $^{99m}$Tc. Of particular concern is that amount of these radionuclides which might become airborne and escape into the environment during the process of manufacture or during aliquotting or administration by hospital personnel. Therefore, the radiopharmaceutical industry facilities have been reviewed to identify those parameters and mechanisms that could lead to the airborne release of radioactive isotopes and assess the control technology employed.

HOSPITAL USAGE

The radionuclides used in nuclear medicine procedures are grouped according to use as follows:

- Internal Therapy - $^{131}$I, $^{198}$Au, $^{32}$P
- In Vivo Studies - $^{99m}$Tc, $^{123}$, $^{125}$, $^{131}$I, $^{133}$Xe, $^{51}$Cr, $^{18}$F, $^{67}$Ga, $^{198}$Au, $^{59}$Fe, $^{111}$In, $^{81m}$Kr, $^{75}$Se, $^{89}$Sr, $^{201}$Tl
- In Vitro Studies - $^{125}$, $^{131}$I
- RIA - $^{125}$I, $^{3}$H, $^{57}$Co

These radionuclides, except for krypton and xenon, are handled in a solid or liquid form and thus are not likely to be released as an airborne effluent. In hospitals, the iodine usage rate is 800-1350Ci/y. Preparation and transfer techniques for iodine tends to retain it in the liquid phase. The emission of airborne radioiodine is minimal during normal operating procedures except for protein-iodination by researchers. Therapeutic $^{131}$I is readily volatilized and can become an airborne contaminant when used in selected therapeutic procedures.

$^{133}$Xe usage rate is estimated at 1600-3000Ci/y. $^{133}$Xe is an inert gas that can be released as an airborne effluent. $^{133}$Xe has a biological half-life of about 1-2 minutes which results in low

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patient dose and is usually administered in 15–25mCi doses for patient imaging. Following administration, the patient exhales the \( {^{133}}\text{Xe} \) gas into a spirometer, either with or without charcoal treatment\(^2\) or a Douglas bag with ultimate exhaust through a roof stack. \( {^{99m}}\text{Tc} \) is currently used in large quantities at hospitals at an annual usage rate of 15,600–30,600Ci/y. It is used as prepared by the manufacturer or is eluted in liquid form from a radioisotope generator (\( {^{99}}\text{Mo} - {^{99m}}\text{Tc} \)) and prepared as needed. \( {^{99m}}\text{Tc} \) is included as a potential airborne effluent primarily because of the quantity used in medical procedures.

On the basis of these considerations and assessment of reports on measurements of effluent radioactivity from hospitals,\(^3,4\) the potential airborne effluents from hospitals were identified as \( {^{131}}\text{I}, {^{133}}\text{Xe}, \) and \( {^{99m}}\text{Tc} \).

**MONITORING OF FACILITIES FOR AIRBORNE EFFLUENTS**

Effluent monitoring data for the isotopes of interest were obtained from seven suppliers and a 1976 State of New Jersey study.\(^5\) That data show that the radioiodine dominates the airborne releases from these facilities. Reports of hospital effluents were mainly concerned with liquid effluents. However, a recent paper\(^6\) detailed the volatilization of radioiodine during preparation and administration of therapeutic liquid \( {^{131}}\text{I} \). A steady-state release rate of 5 nCi/min from a 30 mCi solution was reported. In a literature search, no quantification of airborne effluent releases of radioiodine from hospitals was found.

**CONTROL TECHNOLOGY**

Like the commercial nuclear power industry, the radiopharmaceutical industry evolved under strict federal and state limits on releases of radioactivity to the environment. In general, the suppliers and users of radiopharmaceuticals rely on the guidance of 10 CFR 20, Appendix B,\(^7\) to determine the maximum permissible concentrations (MPC) for radionuclides in air or water that are contained in effluent releases and the workplace environs. Essentially all of the effluent control equipment that was found in use in radiopharmaceutical facilities: (1) was developed in the commercial nuclear power industry, (2) follows proven, reliable designs copied from nuclear power plant equipment, and, (3) consists of off-the-shelf components or complete systems readily available from commercial vendors.

Generally, the means to control airborne radioactive effluents fall into two classes according to function. The controls either: (1) dilute and direct the effluent to a specific point of release, or (2) hold up the effluent to reduce by decay the amount of radioactivity released.

The first class may be described generally as air flow or ventilation controls. These provide no hold-up or time for decay of routine releases except the delay due to the effluent's transit time through the ventilation system. These controls direct the radioactivity from its source within the building into the ventilation system.
and then to the controlled release point. Examples include fume hoods, glove boxes, wall fans, and vent stacks. Each is intended to provide, within a radioactive materials facility, a zone of air pressure lower than in the adjacent nonradioactive areas. The air inflow from adjacent zones also dilutes the radioactivity in the low-pressure zone. Ventilation controls may be used alone but are often combined with the second class of controls (i.e., those that reduce the amount of radioactivity released).

The second class of controls may be described generally as radioactive effluent mitigators. They remove the radioactive materials from the effluent exhaust stream and hold them physically or chemically, reducing by decay the total radioactivity in the effluents. One example is activated carbon, which effectively adsorbs heavy vapors and gases, such as iodine and xenon. Other examples in this class of controls include silver-exchanged zeolites and silver-impregnated alumina and silica. Another example is the cryogenic trap for noble gases, which liquefies them and holds the liquefied gases for decay. For molybdenum and technetium, which may be found in particulate form in the effluent stream, a high efficiency particulate absolute (HEPA) filter can provide effective effluent control.

Suppliers Effluent Controls

From contacts with the radiopharmaceutical suppliers, it was found that the types of effluent controls used depend on the type and amount of each isotope handled in the facility.

Effluent control cost varies widely from installation to installation, depending on such factors as (1) volume of air to be treated, (2) degree of treatment needed, (3) ease of installation, (4) chemical quality of air treated, and (5) equipment reliability. Differences in routine maintenance and monitoring contribute most to differences in equipment performance from site to site.

Activated carbon and/or HEPA filters in the exhaust stream of the building and fume hood ventilation systems appear to be the rule among large radiopharmaceutical firms and common among small firms handling radiiodine or technetium. This equipment appears to function economically, reliably, and effectively and to be the choice for radiiodine control by radiopharmaceutical firms. It is estimated that the average cost of installing such systems to be approximately $8,000 per 1000 cfm, of maintaining such systems to be $1,000/y per 1000 cfm, and the dose reduction provided by such controls to be approximately factors of 10 to 100 for iodine and up to 3333 for technetium (the dose reduction provided depends on operating conditions). Xenon control at supplier facilities presently requires more elaborate equipment for which no good data could be found.

Users Effluent Controls

Because hospitals consume most of the radiopharmaceuticals produced, they were the focus of the study of radiopharmaceutical users' effluent controls. The most significant difference between suppliers' and users' effluent controls is the difference in scale. Small hospitals (less than 300 beds) appear to operate with no radioactive effluent controls because the principal isotope used ($^{99m}$Tc) is
handled in liquid solution and because the total activity handled per
day is low (a few millicuries, typically). Both the medium-size (300
to 500 beds) and large (more than 500 beds) hospitals varied from
using no controls to using extensive controls. Generally, the large
hospitals appear to use controls like those of the radiopharmaceuti-
cal suppliers, because they handle large amounts of activity per day
(tens or hundreds of millicuries) and they handle a wide variety of
isotopes. Controls at the large hospitals range from fume hoods
with HEPA and carbon filters and xenon traps to unfiltered fume hoods
and no xenon traps. The medium-size hospitals tend to use xenon
traps and unfiltered fume hoods, but may have no controls if they use
nuclear medicine as infrequently as small hospitals, or meet NRC MPC
requirements without controls. The carbon xenon trap offers a con-
venient, effective means to reduce xenon releases from hospitals
and is the xenon effluent control preferred by the NRC.

SUMMARY OF EFFLUENT CONTROLS IN THE RADIOPHARMACEUTICAL INDUSTRY

From contacts with radiopharmaceutical suppliers, users, and
effluent control equipment vendors, it was found that the control
equipment is readily available, reliable, and effective in reducing
radioactive releases from radiopharmaceutical facilities. The cost
of controls appears to increase proportionately with the dose
reduction provided by the controls. NRC requirements(6) and owner/
operator perceptions of the controls' cost-benefit ratios determine
what controls are used at a given facility. Based on the above it is
believed that the effluent controls available and used today in the
radiopharmaceutical industry adequately protect the environment and
the public health and safety.

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