THE MEDICAL COMMUNITY ROLE IN RADIOLOGICAL WASTE DISPOSAL

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INTRODUCTION

Radioactive materials are used in medicine to a larger and larger extent. They find clinical application in diagnostic and therapeutic procedures, and form the basis for a large number of research programs. Much of our understanding of the human body stems from tracer investigations in physiology, pathology, and pharmacology. Levels of activity found in medical institutions span an astonishing range from picocuries in the research range to nanocuries in radioimmunoassay, to microcuries and millicuries in nuclear medicine, and on up to kilocuries of radionuclides used as radiation sources in radiotherapy.

Currently in the United States there are approximately 3,400 hospitals using radioactive materials, and 123 medical schools. The medical radioactive waste from these institutions is similar in many respects to radioactive waste from industry, with the possible addition of some biological hazards (viruses, etc.). The largest levels of activity are found in radiation therapy installations, in which radiation sources of thousands of curies of cobalt-60, iridium-192, cesium-137, and other radionuclides are used in the treatment of cancer. These radiation sources are sealed and are returned to the manufacturer for reprocessing when the activity falls below a certain level. Thus the sources used in radiation therapy present problems only in transportation, and do not usually impact on the radioactive waste disposal problem.

Nuclear medicine accounts for the vast bulk of medical radioactive sources that are unsealed, and which therefore must be disposed of through appropriate channels. Nuclear medicine is an outgrowth of tracer studies done during the second World War and shortly thereafter. It has grown from very modest beginnings in the early 1950's to what it is today: a standard service in any large hospital. (Hospitals, to gain accreditation from the Joint Commission on Accreditation of Hospitals, *must either* have a nuclear medicine facility or must have access to one that is reasonably nearby.) Each year in this country 15-20 million nuclear medicine imaging studies are performed, and 80-100 million radioimmunoassay (RIA) studies. Almost all of these procedures generate some amount of radioactive waste which must be disposed of properly.

For the most part American medicine was unaware that radioactive waste disposal presented any problem until 1979, when the site closings led to recognition of the crisis. It was quickly realized that closing of waste disposal sites would affect health care as well as the power industry and other users of the waste disposal facilities. For power and for industrial proc-

esses there might be conceivable alternatives, but for diagnostic medical studies using radioisotopes many of the tests are unique and alternatives are not available. Fortunately there was response over a wide front, and the waste disposal sites remained open. The crisis still exists, however, and a precipitate closing of any one of the waste disposal sites (there are only three remaining in the country at this writing) could bring on a health care catastrophe of great proportions.

CLINICAL USES OF RADIONUCLIDES

Clinical uses of radionuclides in nuclear medicine fall into three general areas: in vivo diagnostic studies, in vitro diagnostic studies, and in vivo therapeutic procedures. In vivo diagnostic studies account for most of the activity used, though the in vitro diagnostic studies account for most of the procedures themselves.

In vivo diagnostic studies include radiotracer studies of the heart, lungs, liver, spleen, kidneys, brain, bones, thyroid, and other organs. For the most part the studies are completely noninvasive, requiring only the injection of a small amount of radiotracer. The radiotracer in most widespread use at the current time is technetium-99m, which has properties close to ideal, for medical applications. It has a 6-hour half-life, no beta radiation, gamma energy in a good range for imaging (140 kev), and great chemical versatility.

The selection of Tc-99m as the most widely used radionuclide deserves some comment here, as it has a bearing on the problem of waste disposal. The half-life of an ideal radiotracer for medical studies would be a time comparable to the time it takes to do the study, so that the tracer would remain detectable long enough to complete the procedure, but would not continue to irradiate the patient long after the procedure had been completed. Six hours is a reasonable half-life for many medical studies, though a few studies require several days to complete and other radiotracers must be used for them. A gamma energy that is too low would result in excessive absorption of energy within the body, decreasing diagnostic information available and unnecessarily increasing the patient radiation dose. On the other hand an excessively high energy would make accurate detection and localization difficult. Technetium-99m with its gamma energy of 140 kev falls into a favorable range for most nuclear medicine radiation detectors (gamma cameras). The absence of beta radiation is extremely important, for the short range of beta rays in the body would make detection from outside the body essentially impossible. Beta radiation would contribute heavily to patient's radiation dose without contributing any diagnostic information. In the case of Tc-99m there is roughly a 10 percent internal conversion rate, giving rise to electrons with energy in the 100-140 kev range, which do deliv-

er a "beta-like" radiation dose that must be taken into account in dosimetry calculations. Finally, the ideal isotope must have chemical versatility; if an isotope of helium possessed all of the above ideal properties, it would still be unsuitable as a medical tracer for most applications. Technetium-99m can be made into chemical forms that are taken up by the liver, spleen, kidneys, lungs, bone, and other organs; it can be labeled to red blood cells, spinal fluid, and many metabolites. The list of Tc-99m compounds available for medical studies is growing constantly.

Radiation doses customarily received by patients having nuclear medicine studies naturally vary with the study, but typical doses would be in the range of 1 rad to the target organ and 0.1 rad whole body dose. By way of comparison a single x-ray of the abdomen delivers approximately 1 rad, and natural background in the United States varies from 0.1 to 0.3 rem/year. The radiation dose the patients get from nuclear medicine studies is comparable to or less than the radiation dose they would receive from corresponding x-ray studies, though of course the information obtained is often different.

In vitro diagnostic studies are those studies in which the radiotracer is not given directly to the patient, but rather is used on a sample of blood, urine, or other fluid or tissue obtained from the patient. The radioimmunoassay (RIA) techniques allow diagnostic studies of substances in the blood and other body fluids with extraordinary sensitivity. RIA techniques can analyze the blood for growth hormone, thyroid hormone, certain viruses, enzymes released from damaged heart muscle, pregnancy, blood levels of certain vitamins, drugs, and other substances. The sensitivity of RIA is unmatched by any other technique currently available. Naturally the patient receives no radiation dose from these procedures. Activity levels commonly used range from a few nanocuries to a few microcuries per procedure. A purified sample of the patient's blood (or other fluid or tissue) is mixed with a radiolabeled antibody, or other suitable tracer, the radionuclide usually being either C-14 or H-3. Because of the short range of the weak beta rays from these radiotracers, liquid scintillation techniques are usually used for detection. The substances to be measured are mixed with the *liquid* scintillation fluor, usually an organic liquid containing a fluorescent substance. The beta radiation is absorbed in the liquid itself, giving rise to flashes of light, which are in turn detected by photomultiplier tubes in an otherwise dark environment. Following the measurements the scintillation fluids must be disposed of. Each sample contains a small amount of radioactivity and in addition the organic fluid (commonly toluene), which must be handled as chemically hazardous waste.

Therapeutic procedures deliberately violate the tracer principle by using a higher dose of radioactive material to bring about a physiologic change in the body. At present there are relatively few types of therapy procedures involving the administration of radioactive materials as unsealed sources. One example would be the treatment of thyroid disease using radioactive iodine (I-131). The thyroid gland is unusual among body organs in that it will concentrate iodine, taking up roughly 20 percent of the iodine in the daily diet. An overactive thyroid can be treated with radioactive iodine, which achieves its effect by interfering with the ability of thyroid cells to replicate themselves at the end of their normal life cycle. Thus over a period of time the number of thyroid cells, and consequently the overall thyroid function, will decrease. Radioactive iodine can be used to totally eliminate thyroid function if it is desired; this is infrequently done, but finds application in certain patients with otherwise untreatable heart disease and some other conditions. Thyroid cancer, though it functions less well than normal thyroid in concentrating iodine, may yet concentrate enough such that if the normal thyroid is removed surgically the thyroid cancer, even if it is spread throughout the body, can be treated with radioactive iodine. Many patients with widespread metastases from thyroid cancer have been cured in this manner, a highly specific form of cancer treatment. To treat thyroid cancer it is necessary to give the patient on the order of 100-150 millicuries of I-131, sometimes on more than one occasion. These high levels require hospitalization, isolation, and stringent radiation safety precautions. All urine from the patient is collected, assayed, and stored for decay.

Radioactive phosphorus (P-32) is used in therapeutic applications in the treatment of certain blood diseases, mainly those involving an excess of a certain type of blood cell (red blood cells, platelets, white blood cells, etc.). A typical dose of P-32 for this application would be on the order of 5 millicuries given by vein. There is no problem of radioactive waste disposal from the patient's point of view, as essentially all of the phosphorus is retained in the body. Radioactive phosphorus as a colloid (chromic phosphate) is used in the treatment of cancer that has spread within the abdomen or chest, in this application being placed directly within the affected cavity. In this application also the activity generally does not leave the patient, though the instruments and tubing used to introduce the radiotracer into the body are contaminated and must be disposed of by appropriate means.

Special problems arise when patients who have received radioactive materials for one diagnostic study are referred for other diagnostic studies also involving radioactive materials. In the case of RIA studies, certain radiotracers given for nuclear medicine diagnostic studies interfere with the RIA meas-

urements. Some radiotracers given for nuclear medicine studies interfere with other nuclear medicine studies, requiring delays; appropriate scheduling of a sequence of radiotracer studies in the same patient is an art. Occasionally special problems arise when a patient who has received radiotracers for diagnostic or therapeutic purposes is then referred for x-ray studies or surgery, or who expires and is brought to autopsy while there is still a significant amount of radioactive material within the body. For example, a patient containing 20 millicuries of technetium-99m would expose another person to a dose of 1.4 mr/hr at a distance of 1 meter, though internal attenuation would tend to reduce this exposure significantly. A thyroid therapy patient having received 3 millicuries of I-131 would expose another person to a dose rate of 0.7 mr/hr at one meter, and a thyroid cancer patient having received 100 millicuries of I-131 would present a dose rate of 23 mr/hr at one meter. Some patients who have received radioactive materials must therefore be considered unsealed sources for purposes of radiation safety.

MEDICAL RADIOACTIVE WASTE

Medical radioactive waste comes in several forms: solids, liquids, animals, and contaminated objects. Many of these forms may have hazards other than their radioactivity: liquids may be inflammable, animals or liquids may be contaminated with viruses, etc. These hazards must also be taken into account in handling, transportation, and disposal.

Medical radioactive waste accounts for a significant fraction of the total volume of radioactive material generated in this country, but for a very small amount of the total activity. In 1978 all sources of radioactive waste generated 83,800 cubic meters requiring disposal, of which the medical community accounted for 21,200 cubic meters, or roughly 25% of the total. In the same year all sources accounted for 886,000 curies of activity, the medical community only 2,500, or 0.3% of the total. Compared to the other sources of radioactive waste, medical facilities would appear to be relatively inefficient in terms of activity per unit volume.

In the same year, 1978, the 2 isotopes used in RIA studies, C-14 and H-3, accounted for 38% of the total activity disposed of. The significance of this will be discussed shortly. The shortlived isotope Tc-99m accounted for 30.9% of the total medical waste. Other identifiable longer lived radionuclides accounted for 18.4% of the total, and miscellaneous (unidentified radionuclides) accounted for 12.7%

In 1979, when site closings and threats of site closings brought the unreliability of the waste disposal system to light, several things happened that brought about significant changes in the medical waste disposal patterns. Many hospitals found

it possible to hold the short-lived radioisotope Tc-99m through 10 half lives (60 hours, or 2½ days), after which time it could be disposed as non-radioactive waste. Not all medical facilities were able to respond in this way, however. Space is at a premium at most hospitals, and identifying new space for the sole purpose of holding radioactive material in escrow was not a practical solution universally. As a result many hospitals still dispose of Tc-99m as ordinary radioactive waste, though as time goes by more and more hospitals are using the escrow system. In recent years there has been increasing use of an ultra-short-lived radioisotope, Kr-81m. With its 13.3 second half-life disposal is not a problem, nor is it in a practical sense for its parent, 4.4 hour Rb-81.

In 1980 the Nuclear Regulatory Commission modified a section of 10 CFR 20 so as to permit the disposal of liquid scintillation fluids and animal carcasses which contained less than 0.05 microcuries of C-14 or H-3, without regard for the level of radioactivity. Clearly, since both of these waste forms contain other hazardous materials, each must be disposed of according to its hazards (flammable chemicals, biological hazards). This modification has since gone into effect. The Nuclear Regulatory Commission has estimated that liquid scintillation vials and animal carcasses which contain C-14 or H-3 represent 50-55% of the medically generated low-level radioactive waste sent to commercial shallow land disposal sites. It is likely that the agreement states will adopt this new rule. If universally used this rule would reduce by 50% the volume of medically generated low-level radioactive waste; since medical volume accounted for 25% of total volume in 1978, one could expect a 10-15% reduction in the overall volume reaching the disposal sites.

Another piece of legislation passed by Congress in December 1980 and signed into law by President Carter is the Low-Level Radioactive Waste Policy Act (P.L.96-573). This act makes each state responsible for figuring out what to do with its own low-level radioactive waste, and allows states to enter into compacts in the search for solutions.

No data are yet available to give a numerical reflection of the impact of these two legislative changes on the pattern of medical low-level radioactive waste disposal. The crisis of 1979 was reflected in a reduction of medical volume as a percent of total volume from 25% to 19%. Much of this was probably accomplished simply by holding short-lived radioisotopes in escrow.

Volume reduction by compaction or incineration has been recommended as a possible approach for medical institutions. For some reason neither of these practices has become widespread. Incineration, certainly the most efficient means of

volume reduction, would still have the potential of releasing measureable amounts of radioactivity into the environment. The public mood regarding such releases is, at the present time, so negative that many hospitals would not even consider such a venture for fear of public reaction.

As transportation and disposal costs rise, volume compaction is becoming more attractive as a means of decreasing the volume/activity ratio. Much of medical low-level waste is in the form of laundry, absorbent materials, syringes, glassware, gloves, and material left over from the preparation of radiopharmaceuticals.

The outlook for the future is basically good. The field of nuclear medicine will continue to develop, and one of its directions will be the use of shorter-lived radiotracers not requiring radioactive waste disposal. Almost all RIA techniques can be carried out at concentrations of C-14 and H-3 well below the cut-off limit, avoiding the need for disposal of RIA residues as radioactive material. Volume reduction, either by individual medical facilities or by central units serving a number of facilities, will create more efficient volume/activity ratios. And finally, the creation of new low-level waste disposal sites will ensure continuity in medical care for millions of Americans whole health is linked to the atom.